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DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION.[1]

PART II. CRITERIA FOR DETERMINING STREAM MODIFICATIONS.

(1) ALIGNMENT OF THE DRAINAGE AFFECTED BY THE MIGRATION OF DIVIDES.

BEFORE attempting to apply the law of the migration of divides, it is well perhaps to consider how its operation affects the arrangement of the minor drainage lines; and thus become better acquainted with the criteria of change which we may expect to find in the field.

(*a*) *Rectangular arrangement of the drainage lines.*— Here again we must begin with the simplest conditions possible and progress to the more complex. Manifestly the simplest condition we can assume is that of a region so long subjected to base leveling processes that its surface is a plain with but slight irregularities, standing at or near sea level. The strata must be practically homogeneous and horizontal. The first of these conditions insures an equilibrium of the streams,—a perfect inter-adjustment of the branches which is impossible under other than base-leveling conditions. The second eliminates the effect of geologic structures and the varied character of the rocks which almost always exerts an important influence. When the external influence of geologic structure and character of rocks is removed

[1] Published by permission of the Director of the U. S. Geological Survey.

from the question the law of migration of divides will cause modifications in all the streams within the area affected by the uplift or depression. This applies to streams belonging to the same system, as well as those belonging to different systems. and operates as follows: Wherever two streams are contesting for a divide, and the surface is tilted in a direction perpendicular to that divide, the streams located on the side of the greatest tilting will rob their adversaries of the contested ground and the divide will migrate indefinitely, depending upon the amount and continuation of the movement and the size of the opposing streams. Under such conditions the smaller streams will extend their head branches directly toward the line of greatest uplift, and consequently will arrange themselves at right angles to, and flow away from the axis of uplift, or toward the axis of depression. The larger streams which cross the axis, will be variously affected by the movement, depending upon the volume of the stream and the rate of the uplift. If the volume of water is great and the uplift sufficiently slow, the river may corrade its channel as fast as it is elevated, and so maintain its position. If the rate of uplift is more rapid than that of corrasion, the stream will become ponded and probably robbed of a large portion of its drainage basin by a more favorably located rival.

The small branches, having assumed a course at right angles to the axis, will carry their waters away from the axis until they pass beyond the region affected by the tilt, or join some longitudinal stream of sufficient size to have maintained its course despite the uplift.

The major streams tend to arrange themselves parallel with the axial line, hence they will flow approximately at right angles to the minor drainage lines, producing a rectangular system. A large stream flowing originally parallel with the axis will tend to retain this parallelism, unless it is tapped by some lower stream, and in that event the chances are that it will be tapped by a stream flowing perpendicular to the axis, and the major stream will be transferred to a lower course. In no case, unless local obstacles interfere, will the stream pursue a diagonal

course; its constant tendency is toward courses at right angles to, or parallel with the axis. If the movement is enough to give the rocks an appreciable dip, the stream, in corrading its channel, will tend to cut its banks on the lower side, and in doing so will migrate down the slope of the beds, but in all such cases the stream will move as a whole, still retaining its parallelism with the axial line. If the stream flows, in general, parallel with the axis, but in a broadly meandering course, the tilting will give to the stream a tendency to cut off its ox-bows and so straighten its course and at the same time migrate away from the axial line. This change is produced by the retardation of the current in that portion of the bend in which the stream flows toward the axis, and an acceleration in that portion in which the stream flows away from the axis. Figure 9 represents such a stream on a

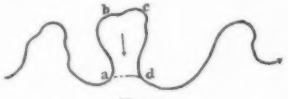

FIG. 9.

surface tilted in the direction of the arrow. In the course *a b* the grade is lessened by the tilting and consequently but little corrasion is accomplished but in the course *c d* the grade is steepened and corrasion is greatly stimulated. As a result of this change in the grade of the stream, the channel at *d* is very much lower than at *a*, hence a small stream may easily work back across the neck of the bend and capture the main stream at the point *a*. This process tends to straighten the course of the stream and at the same time causes it to migrate away from the axial line.

Again the original course of a stream may be neither parallel with, nor perpendicular to the axial line, but may pursue a diagonal course indicated by *A B* in Fig. 10. If such a stream has a branch (*A C*) which flows parallel with the axis, under certain conditions a small branch (*a b*) of the lower stream may cut through the divide separating the two streams and rob the diagonal stream of its upper portion. Ordinarily such a transfer

would probably not take place, for the stream *A B* would probably corrade its channel about as rapidly as the land rose, and so would prevent the lower stream from affecting its capture.

If, however, the arrangement shown in Fig. 10 prevails at the close of a period of quiescence in which the surface is worn down close to baselevel, the streams would be in a position to

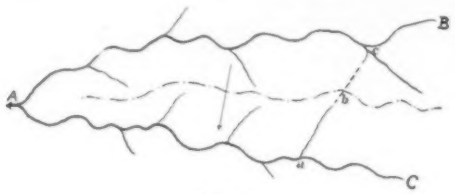

FIG. 10.

take advantage of any opportunity to extend their drainage basins. If at such a time a tilt occurred in the direction indicated by the arrow the point *a* on the stream *A C* would remain at about the same elevation as *A*. The stream *A B* would be accelerated, but active corrasion would, for a long time, be mainly limited to its lower course. The branch *a b* would be greatly accelerated and might be able to cut headwards to the point *c* and capture *c B* before *A B* cuts back to the point *c*. Whether this diversion would be accomplished or not, depends upon the rapidity of the uplift, the volume of water in *A B*, and the character and attitude of the rocks between the two streams.

Thus the migration of divides on a tilted surface tends to produce a system of drainage, the small branches of which are perpendicular to the axial line, and flow in the direction of the dip of the surface; and also a series of branches of the second order, flowing parallel with the axis, and in general coinciding with the downward pitch of the same. When the axis of uplift coincides with a divide already established, it is obvious that the divide will be preserved, but a rearrangement will take place in the head branches of the contending streams. The increased gradient will induce the small branches to extend their upper courses directly toward the axis, and the larger streams will

adjust themselves in a direction perpendicular to the course of the small streams; so the final result will be an arrangement of the drainage similar to that which occurs when the uplift is in any other position.

(*b*) *Unsymmetrical drainage basins.* — When the tilting affects a territory broad enough to include several systems of greater or less extent, a peculiar arrangement is produced which can be

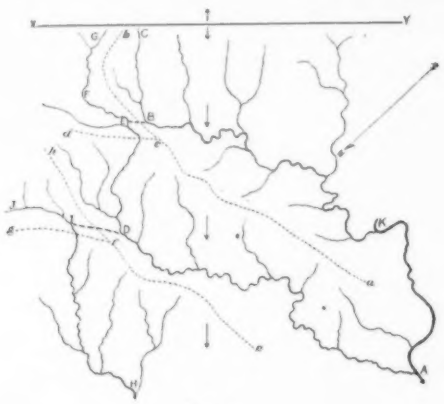

FIG. 11.

easily recognized, and which shows at a glance the direction of the tilt which produced it. The minor drainage lines, as just described, will arrange themselves in general lines at right angles to the axis of uplift, and will unite in trunk streams parallel to the rising fold. Figure 11 represents the drainage on such a broadly tilted surface. The axis is indicated by the line *X Y*. The territory is divided among the streams *A B C*, *A D G*, and *H I J*. It is but reasonable to suppose that before the tilting occurred, these streams were in about the center of their respective basins. As the land rose along the line *X Y* the minor branches on the right-hand side of the larger streams were retarded by the uplift, whereas the branches on the left were accelerated. These accelerated streams crowded the divides farther and farther up the slope and at the same time extended

their head branches directly toward the axis. This produced very unsymmetrical basins in which the trunk streams are flowing on the lower side of the basins, with the minor branches reaching toward the stream next above.

Sometimes these long aggressive tributaries work through the divide and tap the headwaters of the stream next above. In Fig. 11 there are two such cases of robbing; one at the point *E* where the branch *D E* has apparently cut through the divide *c d* and beheaded the stream *A B F G*, and the other at the point *I* where *H I* has robbed *A D I J* of the portion *I J*.

(2) EFFECT OF THE EARTH'S ROTATION ON DRAINAGE LINES.

Kerr[1] observed such an arrangement of the streams of eastern North Carolina, but he attributed their origin to an entirely different cause, viz., the rotation of the earth on its axis. In arriving at this conclusion, he considered the possibility of a tilted surface, but dismissed the idea as untenable. In support of the former hypothesis he cited a few isolated cases which seem to favor his view of the case.

Gilbert,[2] in his study of the effect of rotation, reached the conclusion that the cause is adequate, under favorable conditions, to produce such results, and referred to the drainage of the southern side of Long Island as an illustration of the working of the law.

It is not the purpose of the writer to enter into a discussion of the efficiency of the rotation of the earth in producing drainage modifications of a certain type; but rather to show that such peculiarities are of very common occurrence in places where rotation could hardly have been an active agent, and that some other cause is capable of producing the same effect. As will be pointed out later, changes of just such a character as those described by Kerr in North Carolina and by Gilbert in Long Island can be found in almost every stream of the Appalachian

[1] Geology of North Carolina, 1875, by W. C. KERR, pp. 9–12.

[2] The Sufficiency of Terrestrial Rotation for the Deflection of Streams. Am. Jour. Sci., Vol. XXVII, pp. 427–432.

region. These streams instead of showing the regularity in direction which would be expected if the cause is the rotation of the earth, exhibit an irregular arrangement which clearly indicates that the cause is local and not general. As will be shown later these modifications have a certain definite relation to the great uplift along the Appalachians and seem without much doubt to owe their origin to the tilting which accompanied this uplift. The writer would also suggest that even in the coastal regions there may yet be found evidence of decided elevation, or tilting, of which the visible coastal sediments give no indications.

We have then two theories to account for this class of facts : terrestrial rotation, and the natural adjustment of the drainage upon a tilted surface caused by crustal movements. It has been demonstrated in the previous part of this paper that the latter theory is entirely adequate to produce the given effect, and also that these earth movements have been of frequent occurrence in the past. On the other hand, the sufficiency of the former hypothesis is a matter of doubt, even in the minds of the eminent scientists who have investigated it.

When the practical application of the law of the migration of divides is made, the question becomes very complex. Alternating hard and soft beds, even when they are approximately horizontal, tend to modify the result ; but they are infinitely more potent in shaping the lines of drainage, when they are tilted at various angles, or bent into great folds. At first sight it would seem impossible in such regions to detect any change due to slight surface warpings, but careful study reveals the fact that even here the streams are affected by it, showing by their arrangement the position of the axis of movement and something of the relative steepness of the slopes.

(3) MODIFICATIONS DIFFER ACCORDING TO AGE.

(*a*) *Recent movements shown by barriers and changes of grade.* — The most recent uplifts have not yet affected the alignment of

the streams, for that is a matter of slow development. If the uplift rises athwart the stream, the first recognizable feature is the change of grade in the river profile and the formation of a barrier at the point where the axis crosses the stream. If the stream is flowing over soft, homogeneous rocks, corrasion may take place so rapidly that no appreciable barrier is produced, but as a rule we may expect to find some feature characteristic of a revived stream at this point and ponding in the stream above the barrier.

(*b*) *Remote movements shown by the arrangement of the minor drainage.* — Movements which occurred in the remote past have left no record where they crossed large streams, unless the movement was so severe as to cause reversal but the minor drainage lines may be marked by all of the characteristics described in this paper. The divides may have migrated until all of the stream basins are unsymmetrical, having the main stream near one side and the minor drainage lines reaching out toward the axis of uplift. Unless counteracted by geologic structure, the rectangular arrangement of the drainage lines will be permanent, so long as the crustal movement continues, or until counteracted and obliterated by reverse movements. In such cases if the change has not progressed too far it is generally possible to find cases of stream capture and other marks of radical rearrangement.

(*c*) *Very remote movements shown by the arrangement of the trunk streams.* — As we go farther and farther back into the past, the evidence becomes less and less perfect, until at last it is only in the arrangement of the great streams that we can find a trace of the conditions then prevailing. This of course is unsatisfactory, since it is bare of all details, but in a broad way it outlines the movements which shape the main drainage-ways of that distant age.

(4) PERIODICITY OF STREAM CHANGES.

There is another point which it is well to consider in the application of the law of the migration of divides, and that is,

that the changes induced in the drainage systems are inclined to be periodic in their occurrence. This is extremely important, since it enables us to locate in time many of the changes which otherwise we would be unable to fix definitely.

Streams are so susceptible to prevailing conditions that they do not always respond to the tilting of the surface. There are times when a tilt produces but little effect; then again a slight movement will produce the most profound modifications. If the tilting occurs while the streams are in their youth, it will have but little effect upon them unless it is excessive. In that period of its existence the stream is active, it is cutting its channel vertically, and it is well entrenched in its position, hence a slight tilt of the surface will produce no appreciable effect. If the streams are in their old age, the surface of the land will constitute a peneplain, and if in extreme old age, this peneplain will approach very closely to baselevel. At such times the drainage basins are delicately balanced against each other; not alone are the systems so balanced, but each individual stream is pitted against its neighbors in a balance so delicate that the least outside influence may turn the scale, and the favored stream conquer the ground now occupied by its neighbors. It is at such times that crustal movements are accompanied by the most profound results; consequently we find that a large majority of the changes in the alignment of the drainage systems of the Appalachian region have occurred after a period of extensive baseleveling; they were caused by the first movement which terminated the quiet of the long period of uninterrupted erosion.

(5) CRITERIA FOR DETERMINING THE COINCIDENCE OF LINES OF UPLIFT WITH PREËXISTING DIVIDES.

Since, under favorable conditions, the final result of all long-continued local uplifts has been the migration of the divides to the axial line of the uplift, it would seem difficult, if not impossible, to establish criteria by which to separate the uplifts which originally coincided with divides, from those which were differently located. In a measure this is true, but there are certain

characteristics which seem to mark such uplifts and separate them from the general class.

If a drainage basin, having a long circuitous outlet to the sea, or one which is greatly retarded in its development by hard rocks, maintains its balance against an opposing stream having ready access to the sea, it is altogether probable that this balance has been maintained by an uplift which corresponded originally with the divide between the basins.

PART III. APPALACHIAN DRAINAGE.

The preceding portion of this paper has been devoted to the demonstration of the law of the migration of divides, and in presenting the criteria by which such changes in the drainage systems may be recognized. These criteria are divisible into three classes, indicative of different degrees of change, as follows:

Class 1.—Barriers or obstructions in the channel of a large stream with attendant features which are indicative of very recent movement,—so recent indeed as to have no effect upon the alignment of the stream or any of its branches.

Class 2.—Complete rearrangement of the minor drainage lines. This points to a pronounced warping at a time so remote that all of the lesser streams have become adjusted to it by changing their courses as previously described.

Class 3.—Certain arrangement of the trunk streams, indicative of crustal movements of pronounced character and of very ancient date.

It now remains to examine hastily some of the drainage systems of the United States, to see if we can detect any of these characteristics. In so doing, attention will be confined almost exclusively to the region east of the Mississippi River, as being the one with which the writer is most familiar; and in this Appalachian region we shall consider only that portion which is south of the great terminal moraine, for in glaciated regions the problem of stream modifications is entirely too complex for present consideration.

(1) RECENT MOVEMENTS INDICATED BY THE MUSCLE SHOALS IN THE TENNESSEE RIVER.

The Tennessee River is obstructed, in its course through northern Alabama, by a barrier which is widely known as the Muscle Shoals, and which has been, until the completion of the canal in recent years, a serious bar to the navigation of the stream. In this case there is no possibility of the existence of an old, abandoned channel around the obstruction, such as characterizes the falls of the Ohio River at Louisville, Kentucky. The Tennessee River at the Muscle Shoals is occupying the same channel that it did in late Tertiary time, hence the obstruction in the stream must be accounted for by some hypothesis which admits of the occupancy of the present channel for an indefinitely long time.

Such a barrier can be produced in one of two ways: either the entire region has suffered an uplift and the river has only succeeded in cutting its channel back to Florence, Alabama, or a local uplift has occurred at this point which has elevated a small portion of the stream above its normal grade, and this uplift has been so recent that the stream has not yet been able to remove the barrier. In order to determine which hypothesis best accounts for the facts, it will be necessary to examine closely all of the characteristics of the stream both above and below the barrier.

(*a*) *Profile of the Tennessee River.*—From Chattanooga, Tennessee, to Brown's Ferry, Alabama, a few miles below Decatur, there is a fall of but 49 feet in 185 miles; below Brown's Ferry for a distance of 57 miles the descent is rapid, amounting to a total of 169 feet; below this the grade is again slight, having a fall of only 120 feet in 250 miles.

From these figures it is apparent that there is not only a break in the grade, but also that the elevation of the head of the shoals is above the average grade of the river from Chattanooga to its mouth. This evidence appears to favor local uplift, but it is not conclusive.

(*b*) *Character of the river valley.*—From South Pittsburgh, Tennessee to the head of the shoals, the valley of the Tennessee River is broad and worn down about to the baselevel of the stream at the head of the shoals. Reliable data concerning the character of the valley below the shoals are difficult to obtain, but the preponderance of evidence seems to show that this also is a rather old valley, with all of the side branches cut down to the level of the river. From this it appears that the valley below the shoals is fairly comparable in age and amount of excavation to the valley above the shoals, and that both have the appearance of considerable age. Between these two old portions of the valley lie the Muscle Shoals in which active corrasion is going on today. This result could not have been produced if the region had suffered general elevation alone; hence the question is narrowed down to the theory of a local uplift.

(*c*) *Character of the stream.*—Since the rocks composing the shoals are the hard, cherty beds of the lower Carboniferous, we should expect to find some evidence of ponding above the shoals, if they were caused by a local uplift. According to the Huntsville sheet of the United States Geological Survey and the description given by the Army Engineers[1] who made the survey of the river there are distinct traces of ponding from Brown's Ferry to a point south of Huntsville. All of the phenomena associated with the Muscle Shoals point to a recent and local uplift as the cause of the barrier.

There are many other streams in the Appalachian region which show barriers and gorges of quite recent construction, but in most cases they are due to a general elevation which has simply produced a revival of the stream. A critical study of these obstructions fails to reveal the characteristic features found in the Tennessee River at the Muscle Shoals.

(2) REMOTE CHANGES SHOWN IN THE STREAMS OF THE MISSISSIPPI VALLEY.

The adjustments of this order are confined to the rearrange-

[1] Report of the Secretary of War, Vol. II, 1868–69, p. 584.

ment of the minor drainage lines, hence a study of these will be best facilitated by an accurate drainage map.

Numerous cases of such adjustments can be found in the streams of the Mississippi Valley, where the general horizontality of the rocks keeps the problem free from great complications. In this region we find many cases of the migration of divides and the complete rearrangement of the drainage lines.

(*a*) *Kanawha River basin.*—A noteworthy case of this kind, occurring in the central portion of West Virginia, is shown in Fig. 11, and has been described in the previous portion of this paper as a type example of its kind. *A K* (Fig. 11) is the Kanawha River, *K B C* is the Gauley River, *A D G* is the Elk River, and *H I J* is the Little Kanawha River. The first two streams belong to the Great Kanawha system and the last to the Little Kanawha or Ohio River system. As previously explained, the divides have migrated toward the southeast, until in places they are within a mile of the stream next above. It will be noticed that this action is much more effective near the heads of the streams, for at this point alone has capture resulted. Lower down, the divide still remains close to the stream above, but diverges more and more until, as it approaches the mouths of the streams, it is about equally distant from the stream above and the stream below. This is doubtless due to the fact that most of the shifting occurred when the region was uplifted and tilted, after the cutting of the extensive peneplain which is a marked feature of the region. The large volume of water in the lower courses of these streams enabled them to maintain their former courses and quickly intrench themselves within the tilted plain. Since then their cutting has been so rapid that it has overbalanced all of the effects of the tilt; consequently their basins, in this portion of their courses, are approximately symmetrical. Farther up the streams, where the volume of water was less, the streams were unable to so fortify themselves, and consequently were dispossessed of most of their territory by their lower neighbors. At their extreme heads, the streams were held for a long time on the surface of the peneplain, and

the tilting exerted its full force in producing a rearrangement of the drainage lines. The result of this exposed condition is that most of the streams have been captured by branches working back from the northwest producing the imbricated arrangement shown in Fig. 11.

In the light of the previous discussion, there seems to be no question that this condition is due to a gentle tilting of the surface toward the northwest from near the Greenbrier River. In this region the inter-stream areas are of such an elevation that the principal migration must have occurred long ago—when the general surface was many hundreds of feet higher than today, and at a time when the surface relief was slight. There were probably two periods when such a change could have taken place, contemporaneously with the completion of either the Cretaceous or the Tertiary peneplains. The character of the changes point rather to the latter than to the former; for if the tilting had occurred in Cretaceous time, subsequent changes would, in all probability, have obliterated the courses of the minor streams. But it is the minor drainage lines which are here the characteristic features and which were probably formed long after the uplifting of the Cretaceous plan from baselevel.

(*b*) *Big Sandy and Clinch River basins.*—Southwest of New River, the streams flowing directly to the Ohio are encroaching upon the streams of the Tennessee system, although the latter has a decided advantage in the soft limestones and shales of the Appalachian Valley. Tug fork of Big Sandy River has cut entirely across the coal field, and its head is within a mile of Clinch River at a point fifteen miles below the source of the latter.[1] Not only has it encroached to within such a short distance, but it is flowing more than 300 feet below Clinch River at the point of its nearest approach. In its backward cutting it has reached the Valley limestone and, if conditions remain unchanged, it will be but a short time, geologically speaking, until it will capture Clinch River at this point. The migration of this divide is in the same direction as the cases already cited and is evi-

[1] See the TAZEWELL Atlas sheet of the U. S. Geological Survey.

dently the result of the same cause. This is doubtless the uplift already described by C. W. Hayes and myself;[1] an uplift which accelerated the northwestward flowing streams, but retarded Clinch River by crossing that stream some distance below its source.

(*c*) *River basins of Kentucky.*—The state of Kentucky, lying almost entirely within the undisturbed region of the Mississippi Valley, presents a fine field for the study of drainage forms. A glance at the map of the state shows that even in that region of nearly horizontal rocks the drainage is not well balanced, the stream basins are not symmetrical, and the divides are apparently migrating. Shaler recognized these peculiarities, but he was unable to offer an adequate explanation. He writes as follows:[2] "It is not easy to account for this irregularity in the disposition of the streams away from the mountain regions. Away from those disturbed regions there are only slight irregularities in the rocks, which do not seem to have any power of determining the range of a river basin." He then suggests that their peculiarities may be inherited from conditions in previous ages, when the distribution of hard and soft rocks was very different from that which prevails today.

In the light of the present study, the arrangement of the drainage lines of Kentucky is not peculiar; in fact much of it is most natural and what we would expect, if the surface slopes from the interior toward the Ohio River. The divide on the north side of Cumberland River is apparently encroaching on that stream under an influence similar to that which permits Big Sandy River to encroach upon Clinch River. This encroachment is so pronounced that at one time it was proposed to divert the waters of the upper Cumberland into Goose Creek, a branch of the Kentucky River. The headwaters of Green River also are crowding back toward the southeast against the Cumberland basin and have now approached to within a very few miles of the main river. These divides must have migrated toward the

[1] Geomorphology of the Southern Appalachians, Nat. Geog. Mag., Vol. VI, p. 94.

[2] Kentucky Geological Survey, Vol. III, New Series, p. 360.

latter stream, hence we conclude that the prevailing tilt of the surface has been toward the northwest and away from the Cumberland River.

Some of the peculiarities cannot now be satisfactorily explained even on this basis, but the writer believes that it is because of the lack of reliable data and of the complexity of the problem. They are doubtless due to the same cause, but in all probability it has not always acted in the same place, nor in the same direction.

(3) REMOTE CHANGES SHOWN IN THE STREAMS OF THE ATLANTIC SLOPE.

Throughout the gulf coast of the Atlantic slope there are numerous examples of migration of divides and the consequent unsymmetrical condition of the stream basins. The limits of this paper will not permit of a full discussion, so only a few can be mentioned.

(*a*) *Chattahoochee River.*—The most pronounced case of the kind is the encroachment of the Atlantic streams upon the Chattahoochee River. From Columbus, Georgia, to its headwaters, the drainage basin of this river is limited almost entirely to its northwestern side. Figure 12 shows the arrangement of the drainage lines in the region about the headwaters of the Chattahoochee River. *A B* is the Etowah River; *C D*, the Chattahoochee River; *G*, the Oconee River; *H*, the Broad River; and *K L*, the Savannah River. The Atlantic streams, or those flowing toward the southeast, have symmetrical basins in which are developed beautiful dendritic drainage lines. The small branches are numerous and have straight, regular courses at right angles to the main line of the Chattahoochee River This arrangement of the minor drainage lines is indicative of a strong southeastward slope of the surface. These minor streams have not only arranged themselves parallel with the line of greatest slope, but they have also extended their courses headwards, until at one point they are within a mile of the Chattahoochee River and at least 100 feet below it.

At this point, which is in the vicinity of Gainsville, Georgia, the capture of the Chattahoochee is imminent, and if conditions remain unchanged, will doubtless be accomplished in the near geologic future. In the vicinity of Tallulah Falls the same process has been carried on, but in this case it has reached completion, and the Savannah River has cut through the divide and

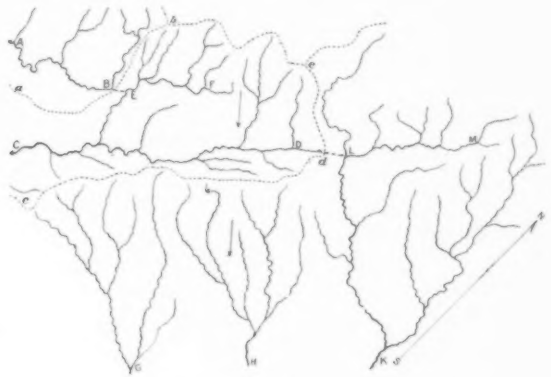

FIG. 12.

captured the portion *L M*, which formerly constituted the headwaters of the Chattahoochee.

The minor drainage lines in the Chattahoochee basin have also arranged themselves parallel with the line of greatest slope of the surface. They, in turn, are encroaching upon the drainage basins to the northwest, although their headward progress is greatly retarded by the mountainous character of the divide upon which they are encroaching. At the point *E*, however, a small branch of the Chattahoochee has already succeeded in capturing the stream *E F*, which doubtless previously belonged to the Etowah River.

This example is somewhat complicated by complex geologic structure, but the arrangement of the minor streams across this structure appears to be evidence of even a more pronounced tilting of the surface than that which has caused such a radical

rearrangement of the drainage in West Virginia. The fact that the extreme head branches of the Atlantic streams have been enabled to cut below the bed of the Chattahoochee seems also to show that these streams have had a decided advantage since the elevation of the Tertiary peneplain to its present altitude.

(4) REMOTE CHANGES SHOWN IN THE STREAMS OF THE APPALACHIAN VALLEY.

So far we have considered only those cases in which geologic structure has played little or no part in shaping the courses of the streams. While in such cases the effect of surface tilting is most pronounced, it has also operated in the Appalachian Valley where geologic structure dominates the whole topography.

No one can consider for a moment the drainage basins of the Susquehanna, Potomac, James, and Roanoke rivers without being impressed by their unsymmetrical condition. In the case of the Roanoke and New rivers, there can be no doubt that the former is encroaching upon the grounds of the latter. This is so apparent that a traveler on the railway easily distinguishes the difference in grade on the two sides of the waterparting between them. In this case, although the divide may now be migrating toward New River, it is very certain that this has not continued for a long time, else New River would have been captured long ago. Here we are not concerned about the migration of the divide, but rather about its non-migration. Since for a long time, New River must have been working at a great disadvantage against Roanoke River, why has not the latter cut through the divide at Christiansburg and captured the entire head of the former stream?

As has been explained, the preservation of a divide under unfavorable circumstances is no more anomalous than the migration of a divide toward the axis of uplift; it simply indicates that the unfavorably located stream has been assisted in the preservation of its drainage basin by an uplift which corresponded with the preëxisting divide between the contending streams; and which by its continued movement has prevented the aggressive stream from absorbing its weaker neighbor.

The constantly increasing magnitude of the river basins in the Appalachian Valley from New River to the Susquehanna, at once suggests the idea that the northern streams have been more favored in their development than the southern streams, and as a result have grown largely at the expense of the latter. Roanoke River has but a few square miles of its basin within the rocky walls of the Blue Ridge; James River has pushed farther toward the northwest, but is still confined well within the limits of the zone of folded rocks; Potomac River controls much more of the area in question and is practically limited in its northwestern side by the Alleghany front; Susquehanna River has not only gained control of a large portion of the valley, but has also extended its headwaters far back into the Alleghany plateau of western Pennsylvania and southern New York. It is at once obvious that these streams are working under different conditions; and judging from their arrangement, it is probable that much, if not all, of this difference is due to difference in amount of interior uplift, and also to the location of the axis of the movement.

The water parting between the Atlantic streams and those belonging to the Ohio River drainage basin forms a remarkably regular line which crosses the valley obliquely from the Blue Ridge south of Roanoke, Virginia, to McKean county, Pennsylvania. From the criteria already established this would appear to mark the position of an axis of uplift which has been mainly instrumental in shaping the drainage basins on either side.

From the James to the Susquehanna the basins are decidedly unsymmetrical; the divides have migrated toward the southwest, until the divide between the Susquehanna and the Potomac approaches close to the left bank of the latter stream, and the divide between the Potomac and the James allows to the former about twice as great an area as it does to the latter. This migration is certainly due to a tilting of the surface toward the northeast, which favored the development of the Susquehanna at the expense of the Potomac, the Potomac at the expense of the James, and the James at the expense of the Roanoke River.

Examples may be multiplied indefinitely, but enough has been cited to show that Appalachian drainage has all of the marks which theoretically we should expect to find on a tilted surface.

(5) VERY REMOTE CHANGES SHOWN IN SOME OF THE APPALACHIAN RIVERS.

In passing still farther backward in geologic time, the minor drainage ceases to be our guide; and we are limited to the big trunk streams from which to read the history of events. Almost every large stream of the Appalachians gives some hint of the surface conditions under which it was formed.

(*a*) *Chattahoochee drainage line.*— The limits of this paper will not permit the mention of all the probable examples, only a few of the most striking will be given. Perhaps the most pronounced example of the kind, and at the same time one that carries the history back the farthest, is that of a series of streams on the eastern side of the Blue Ridge, the arrangement of which appears to have been determined by the depression which preceded and made possible the deposition of the Triassic sediments of the eastern part of the United States. A glance at a map reveals the fact that the course of the Chattahoochee River above Columbus, Georgia; the Savannah above Tallulah Falls; the French Broad above Asheville; and the upper portions of the Catawba and Yadkin rivers occupy almost continuously a line from the margin of the Cretaceous sediments of the Gulf coast to the Triassic deposits of the Dan River area. This continuity of drainage lines at once suggests some common cause, for it seems highly improbable that their location along this line was simply fortuitous. According to the principles laid down in the preceding parts of this paper, such an arrangement could have been brought about by a subsidence the axis of which corresponds with the present drainage lines.

(*b*) *Triassic areas in the same line.*— The areas of Triassic rocks in this region are generally regarded as remnants of a more extended deposit which took place in troughs formed by

local subsidences. The remaining areas of these rocks seem to range themselves in two approximately parallel lines. The westernmost line consists of the Dan River[1] and Danville areas, Scottsville and Barboursville areas, and the great New York-Virginia area stretching in an almost continuous line from Germantown, North Carolina to Stony Point, New York. This is the direct continuation of the Chattahoochee drainage line, and, strangely enough, it is apparently continued to the northward by the valley of the Hudson River and Lake Champlain. The easternmost line, consisting of the Wadesboro and Deep River areas, the Richmond area and the Connecticut area, roughly parallels the first, and it has a northward extension in the Connecticut River Valley. Whether or not it ever had a southwestward extension similar to the parallel line cannot now be determined, for post-Triassic erosion and sedimentation have removed all traces of such streams if they ever existed.

These parallel lines are everywhere marked by stream valleys or areas of deposition, therefore by our criteria they should mark the axes of parallel depressions. These depressions seem to have reached their maximum near the center of the line, for in this portion the sediments probably formed a continuous sheet, indicating that the old land surface had sunk entirely below water level. This maximum submergence appears to have been along a cross axis, or one extending in a northwest and southeast direction; and to this cross depression is probably due the location of the Susquehanna River, the largest and most vigorous of the central Atlantic streams. Judging from the direction of the flow of the streams located along the longitudinal axis, it seems probable that the depression reached a minimum at the southern line of North Carolina, for at that point the waters divide toward the southwest and the northeast.

If our interpretation is correct, these are some of the oldest streams in the United States. With the one exception of the upper portion of Savannah River, which formerly belonged to the

[1] The names of the various areas of Triassic rocks are taken from Correlation Papers — The Newark System, by I. C. Russell, Bulletin No. 85, United States Geological Survey.

Chattahoochee system, it seems probable that they have persisted in the course then determined up to the present time. This interpretation also presupposes the existence of a peneplain at the time the depression occurred, for with the present rugged topography along this line almost no amount of tilting could produce such a radical rearrangement of large streams as that which inaugurated Triassic deposition. This conclusion is perhaps the most important result of the present study, for it appears to verify the statement of Davis[1] that the Atlantic slope was reduced to a peneplain before the deposition of the Triassic sediments. In order to permit the formation of such longitudinal streams, the peneplain must have been practically continuous along the axis of the western fold, and hence today must be at an altitude at least equal to that of the main summits which cross the line.

(6) UTILITY OF THE STUDY OF DRAINAGE FEATURES.

It now remains but to add a word concerning the utility of this study. If the writer has succeeded in establishing the proposition that streams suffer modifications during crustal movements, no one can deny that a careful study of such modifications is extremely important in determining the principal movements in recent geologic ages. If it will do that, it is practically as efficient as the study of physiographic forms. The writer does not wish to be understood as advocating the replacement of the study of physiographic forms by the study of drainage forms, but rather to use the two in conjunction; in other words, to study the forms assumed by the instruments of erosion at the same time that we are studying the land forms produced by these same instruments—the streams. The results cannot be at variance and the studies will be a mutual advantage, one to the other.

MARIUS R. CAMPBELL.

UNITED STATES GEOLOGICAL SURVEY.

[1] The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, by W. M. Davis, Bulletin Geological Soc. Am., Vol. II. p. 549.

ON THE MONCHIQUITES OR ANALCITE GROUP OF IGNEOUS ROCKS.

As is well known to all petrographers the name of monchiquite was first given by Rosenbusch[1] in 1890 to a series of dark basic dikes occurring in connection with intrusions of eleolite-syenite in Brazil. Similar rocks had been previously known from South Portugal and hence they received their name from the Serra de Monchique.

The material from Brazil was investigated by Hunter and Rosenbusch, and the rocks which have a basaltic habit were found by them to consist of ferro-magnesian minerals in a glass base. The ferro-magnesian minerals were found to be always olivine and pyroxene, while with them were associated sometimes amphibole, sometimes biotite, and sometimes both, and according to these variations the group was subdivided.

Since then these rocks, of slightly varying types, have been found, usually in connection with intrusions of alkali syenites, in various parts of the world. In this country they have been found in Arkansas and in numbers in the Lake Champlain district, and our knowledge of them is chiefly due to the researches of Kemp.[2]

In all cases the main characteristics of the types described are that the rocks consist of ferro-magnesian minerals, chiefly olivine and pyroxene, lying in what is called a colorless glass base.

The only case in which, so far as we know, this colorless base has been investigated was in the original study by Rosenbusch and Hunter, in which it was separated and analyzed and

[1] Tscher. Min. Mitt., Vol. XI, 1890, p. 445.

[2] Trap Dikes, Lake Champlain Region; Bull. 107, U. S. G. S., 1893. Igneous Rocks of Arkansas; Ann. Rep. 1890, Vol. II, p. 392 (with J. F. WILLIAMS).

found to consist chiefly of silica, alumina, soda and water. Thus, as Rosenbusch pointed out, it had certain analogies with an eleolite-syenite magma from which the partial magma forming the dikes is supposed to be formed by differentiation of the lime, iron and magnesia. On account of the water it is called a pitchstone glass.

Within the past few years the attention of the author has also been directed to this group of rocks by their occurrence in parts of Montana now being studied in conjunction with Mr. W. H. Weed, under the auspices of the United States Geological Survey. When they first appeared the characterization of them as consisting of ferro-magnesian minerals in a glass base, given by previous authors, was accepted, and one of them so described (in the report on the geology of the Castle Mountain mining district, now passing through the press).

As, however, the number of examples increased and the rocks were studied in connection with their geologic mode of occurrence, it became a source of perplexity as to why such basic magmas, solidifying under the conditions which the general geology of the region evinces, should have formed so much glass.

For it must be said that *a priori* one would scarcely expect to find such basic magmas as form the monchiquites, producing glass when solidifying at such depths as they have in the cases which have come under our own observation, and in the instances which have been described by others. This anomaly is all the more marked when the acid dikes and intrusive sheets which so generally accompany them, and which must have been formed under similar conditions, are taken into account. As is well known the acid magmas crystallize with more difficulty than the basic ones; rhyolitic glasses are well known and are common, while tachylites are rare; at the same depths and under the same conditions which cause the very acid magmas to form extremely fine-grained dense or porphyritic rocks the basic magmas crystallize into moderate or even coarse-grained evenly granular ones. If the monchiquites contained so much glass

one would expect all the more to find the acid complementary forms — the oxyphyres — which accompany them also in, at least partly, glassy forms. This, however, is not the case in any of the regions, so far as we know, in which these rocks have been found, where erosion has cut down so as to expose the deeper-seated intrusive types.

The question thus raised on geological grounds concerning the glassy nature of the base was sought to be settled by other means. Since the microscope failed to yield any decisive results, recourse was had to chemical methods. In a number of samples that have been analyzed were some free from biotite and ægirite, and in which consequently all of the alkalis and presumably the alumina and water were in the base. In such cases it is noticed that the molecular ratios of these elements have approximately the relation:

$$Al_2O_3 : K_2O + Na_2O : H_2O :: 1 : 1 : 2.$$

If sufficient silica is deducted to satisfy the lime, iron and magnesia as pyroxene and olivine, the remainder has an approximately molecular relation to the above as follows:

$$S : O_2 : Al_2O_3 : Na_2O + K_2O + H_2O :: 4 : 1 : 1 : 2.$$

These, however, are the ratios given by the chemical formula of *analcite*. The results, of course, cannot be very accurate, as the exact composition of the crystallized minerals is not known, but are sufficiently close to show that grave doubts must exist concerning the glassy character of the base. Evidently to settle the question the base would have to be separated and analyzed. This has fortunately already been done by Hunter and Rosenbusch in their original investigation, and, as the results to be presently given will show, with great care and skill, on excellent material.

In separating the base from the included minerals by heavy solutions it was found impossible to obtain it absolutely free from microlites of ferro-magnesian minerals, and as Rosenbusch states, a portion of these were attacked by the acid used

in decomposing the substance and went into solution. The analysis by Hunter[1] gave the following results:

SiO_2	53.43	.890
Al_2O_3	20.86	.202
Fe_2O_3	2.61	.016
MgO	.29	.007
CaO	1.14	.020
Na_2O	11.63	.187
K_2O	2.51	.026
H_2O	7.06	.392
	99.53	

The substance just sank in the heavy liquid with specific gravity of 2.31, and this may be taken as being very close to its own specific gravity.

Of the above analysis about 96 per cent. is made up of silica, alumina, alkalies, and water, the rest is composed of the oxides of the microlites taken into solution. It will be seen that the oxides first mentioned are very close in their molecular ratios, given in the second column, to 4 : 1 : 1 : 2, but a slight excess of silica belonging to the lime, iron, and magnesia is present. The state of oxidation of the iron is uncertain, as it is not mentioned whether ferrous iron was determined or not. If we assume that the lime, iron, and magnesia are present according to the general formula of the amphibole group, $RSiO_3$, the microlites having been determined as amphibole, and deduct the requisite number of silica molecules to satisfy them, the remainder becomes

SiO_2	.831 = 4.11	= 4
Al_2O_3	.202 = 1	= 1
$Na_2O + K_2O$	.213 = 1.05	= 1
H_2O	.392 = 1.94	= 2

The base has therefore the chemical composition $Na\ Al(SiO_3)_2\ H_2O$, with a little of the soda replaced by potash, or, in other words, it has *the exact chemical composition, the exact specific gravity, the property of gelatinizing with acids, and the optical*

[1] Op. cit., p. 454.

properties of analcite, and must therefore be that mineral and not a pitchstone glass, as had formerly been supposed.

The sharpness of the ratios given above is an excellent testimonial to the purity of the material, the care with which it was separated, and to the analytical skill of Hunter.

Thus the supposition that the base of these rocks was very unlikely to be a glass, and the indications previously mentioned that it was analcite, are most strikingly confirmed by these results. It is not to be wondered at that a base of analcite should have been mistaken for a glass by many petrographers, including the author, since, the grains having everywhere the same optical orientation and the same index of refraction, there would be no means of distinguishing them in plain or in polarized light, either from one another or from a continuous isotropic substance like glass. In the original monchiquites from Brazil, specimens and sections of which the author owes to the kindness of Professor Rosenbusch and of Professor A. Lacroix from material collected by Professor O. A. Derby, the analcite often shows a tendency to crystal form by the production of areas which are free from the larger prisms of the ferromagnesian minerals, the latter being arranged around them in wreaths. The areas thus resemble phenocrysts of leucite and they are in reality *phenocrysts of analcite*. They are sprinkled full of the microlites of hornblende described by Rosenbusch, which do not, however, show any tendency to the zonal arrangement shown by such inclusions in leucite.

It is a matter of great interest to recall in this connection that Lindgren[1] only a few months previous to Hunter and Rosenbusch had published an account of certain basaltic dikes occurring in the Highwood Mountains of Montana. They were shown to consist of augite, olivine, iron ore and analcite as phenocrysts in a groundmass of magnetite grains, augite microlites and a second generation of analcite.

The analcite was separated and two analyses were made which are given in I and II.

[1] Proc. Cal. Acad. Sci., Series 2, Vol. III, July 1890.

	I	II	Average	Molec. Ratios
SiO_2	54.90	49.87	52.38	.873
Al_2O_3	23.30	22.55	22.92	.222
Fe_2O_3	trace	1.51	0.75	.005
CaO	1.90	2.62	2.26	.040
MgO	0.70	1.28	0.99	.024
Na_2O	10.40	10.92	10.66	.171
K_2O	1.00	2.66	2.13	.022
H_2O	7.50	11.05	7.50	.416
	100.30	102.46	99.59	

Since the analyses were made on very small quantities the ordinary analytical errors become considerable and it is, therefore, probable that the average of the two would be more correct than either alone. The water in No. II is evidently too high and may be excluded. The average is shown in the third column and its molecular ratios in the fourth. The lime, iron and magnesia are of course due to admixed microlites of pyroxene, and deducting sufficient silica to turn them into the general formula $RSiO_3$ the remaining ratios have the following relations:

SiO_2 - - - - - - $.799 = 4.1 = 4$
Al_2O_3 - - - - - - $.222 = 1.1 = 1$
$Na_2O + K_2O$ - - - - $.193 = 1.0 = 1$
H_2O - - - - - - $.416 = 2.1 = 2$

which gives the analcite formula $Na\,Al\,(SiO_3)_2H_2O$ with a fair degree of exactness, some of the soda being replaced by a little potash as in the Brazilian rocks.

In his article Lindgren[1] speaks of the difficulty of distinguishing the isotropic analcites from glass and in a review of the paper Iddings[2] emphasizes this point and suggests that isotropic minerals may have been determined as glass in some cases. It is now becoming evident how often this has, in all probability, been done.

It is now clear from what has been stated above that the

[1] Op. cit., p. 55. [2] JOURNAL OF GEOLOGY, Vol. I, p. 638.

monchiquites of Rosenbusch and the analcite basalts of Lindgren are the same thing, the only difference being that the Highwood Mountain types are lacking in the amphibole found in the Brazilian ones.

In the Highwood Mountain types, as described by Lindgren, the analcite phenocrysts are sharply idiomorphic, which must have been one factor in preventing Lindgren from falling into the error concerning their nature which so many petrographers have committed. Moreover from this fact it would appear that the Highwood Mountain types are the best crystallized and most individualized type of monchiquites which have yet been described. Rosenbusch indeed classifies them with this group in the last edition of his Massige Gesteine.[1]

It now seems probable that analcite as a rock component is not limited strictly to the monchiquite group. The base described in basaltic rocks by Bücking[2] (*Basis zweiter Art*) as a colorless glass containing water, or which is stated to have the general composition of nephelite, that is, consisting of silica, alumina and soda and which gelatinizes readily with acids, is more than probably analcite, and it is quite possible that all of the colorless glasses which have been described as gelatinizing readily with acids have this composition. It seems very unlikely that a glass consisting of silica, alumina and soda would be readily attacked by acids and gelatinize; the basic glasses rich in lime, iron and magnesia and approaching a slag in composition, that is an approximation to the formula R_2SiO_4, are at times readily dissolved by acids, but it is strongly to be questioned if a soda-alumina glass would be. The determination of a colorless isotropic substance containing silica, water, soda and alumina and which gelatinizes with dilute acids in a rock is as safe a determination of analcite as that of the majority of minerals determined in eruptive rocks.

In the discussion of the primary or secondary nature of the

[1] Third edition, 1895, p. 542–543.

[2] Basaltische Gesteine, etc., Jahrb. k. k. preuss. geolog. Laudesanst. 1880 and 1881.

analcite in the rocks investigated by him, Lindgren was forced to conclude from the very fresh and unaltered character of the material that it must be of primary origin. The examination of the Highwood rocks by the author confirms this view of Lindgren's. Anyone who has seen the fresh unaltered character of the minerals in these rocks, not only from Montana but from Brazil and from other localities, would find it difficult to explain how the base could have undergone a thorough chemical change and decomposition throughout without the other minerals being affected in the slightest degree and especially the olivine, of all minerals perhaps the one most delicately susceptible to processes of hydration. It actually appears that henceforth we must accept analcite as an important and common rock-forming mineral, almost unquestionably one may say of primary origin. It is understood of course that its occurrence as a secondary mineral also, is not for a moment denied or its importance underrated. It must be said, however, in view of the facts now presented, that many cases where it has been called a secondary mineral are at least doubtful. Many authors for example cite it as secondary after leucite, and one gathers the impression from the context that this is supposed to have happened by weathering; though how leucite, which is a potash compound, is to change into analcite, a soda compound, by the simple addition of water, is not stated. It is true that Lemberg has shown that leucite is changed into analcite by the action of soda solutions; but, as in the case of the monchiquites, it can hardly be supposed that such an action could have taken place without altering the other minerals, and it would be difficult to see where so great a quantity of soda, as would be required, could have come from. It is also difficult to see how it could have formed from nephelite, norian or sodalite without the formation of other secondary products as noted above.

Lindgren[1] suggests that the mineral could have formed from igneous magmas, provided that the magma contained water and crystallized under sufficient pressure to retain it, and cites the

[1]Op. cit., p. 52.

presence of water in undoubted pitchstone glasses as a proof that water may be retained by igneous magmas at high temperatures. We believe this explanation to be the correct one and will present some further proofs of its probability.

The intimate relation between biotite on the one hand and olivine and leucite or orthoclase on the other was pointed out by Iddings[1] and has been further discussed by Bäckström[2] and the author.[3] Iddings and Bäckström point out that since for the production of biotite certain mineralizing agents, such as water and fluorine, are necessary, since they enter into its composition, the biotite rich rocks must be intrusive ones, whereas if the magma attains the surface and under the diminished pressure the water escapes, then olivine and leucite may be produced. By this is explained the general absence of leucite in abyssal rocks and its frequency in extrusive lavas. This process would of course find its most natural expression in magmas rich in magnesia and potash.

When we consider the magmas in which soda predominates however, it is clear that quite different processes will take place. There is no such relation between soda and magnesia as is shown by potash and magnesia in the biotite molecule. Therefore we might expect that if the magma contained water vapor and soda predominated in it, that analcite would be formed if the magma crystallized under pressure with considerable rapidity, whereas if the magma were anhydrous or the water vapor could escape without taking part in the crystallization either by relief of pressure or by very slow and gradual processes of crystallization, which would exclude it, then we should expect nephelite to form or nephelite and the albite molecule, the latter, perhaps, giving rise to plagioclase.

From this it would follow that the conditions most favorable for the production of primary analcitic rocks would be in dikes and small intrusions which is in fact the place where they occur,

[1] Origin Igneous Rocks, Bull. Phil. Soc., Washington, Vol. XII, p. 176, 1892.

[2] Geol. Fören. Förh., Stockholm, Vol. XVIII, p. 161, *seq.*, 1896.

[3] Highwood Mts. Bull. Geol. Soc. Am., Vol. VI, p. 409, 1895.

while the larger bodies of magma would tend to form theralites, ijolites, etc., and the surface lavas would appear as nephelite tephrites, basanites, basalts, nephelinites, etc.

As a corollary of this it would follow that all of these rocks should possess a general similarity of chemical composition, which in fact they do, as may be seen from the following table of analyses:

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	46.48	43.74	43.50	43.85	43.17	51.03	44.85	42.12	42.88
Al_2O_3	16.16	14.82	18.06	15.25	15.24	8.48	18.08	14.35	13.99
Fe_2O_3	6.17	2.40	7.52	7.03	7.61	11.95	7.71	13.12	15.72
FeO	6.09	7.52	7.64	4.57	2.67	3.21	3.23		
MgO	4.02	6.98	3.47	4.47	5.81	6.34	4.16	6.14	3.94
CaO	7.35	10.81	13.39	8.54	10.63	6.96	9.97	13.00	12.64
Na_2O	5.85	3.08	2.00	4.22	5.68	5.42	3.19	4.11	4.73
K_2O	3.08	2.90	1.30	4.04	4.07	4.83	2.82	2.18	3.96
H_2O	4.27	2.94	1.22	1.80	3.57	1.68	2.56	3.42	3.08

I Monchiquite, Brazil (Hunter and Rosenbusch *op. cit.*), Hunter anal.

II Monchiquite, Brazil (Hunter and Rosenbusch *op. cit.*), P. Jannasch anal.

III Monchiquite, Magnet Cove, Ark. (Williams Igneous Rocks, Ark., 1890, p. 295), W. A. Noyes anal.

IV Monchiquite-Camptonite, Bohemia (Hibsch Tscher. Mitt. XIV, 1894, p. 101), F. Hanusch anal.

V Theralite, Crazy Mts., Montana (Wolff Petrog. Crazy Mts., 1885), J. E. Wolff anal.

VI Theralite, Crazy Mts., Montana (Wolff Petrog. Crazy Mts., 1885), A. M. Comey anal.

VII Nephelite tephrite, Bohemia (Hibsch *op. cit.*, p. 109), F. Pfohl anal.

VIII Nephelite basalt, Löbauer Berg, Heidepriem (Zirkel Petrog., 2d ed., Vol. III, p. 37).

IX Nephelinite, Laach., Eifel, vom Rath (Zirkel Petrog., 2d ed., Vol. III, p. 61).

The list might be greatly extended but the above are sufficient to show that the magmas producing these rocks have certain chemical characteristics in common, low silica, moderate alumina and alkalies with soda predominating over potash, and high lime, and iron, and high to moderate magnesia.

In this connection the author cannot refrain from pausing a moment to call the attention of petrographers to the fact, apparently not often recognized, that analyses of basic rocks, rich in

ferro-magnesian minerals, are very often vitiated by a failure to properly separate alumina from magnesia. Many analyses which would otherwise be good are spoiled by this error. The writer's attention has been strongly called to this point on examining, in connection with this article, various analyses of basic rocks. The types are described as consisting chiefly or largely of pyroxene with or without olivine and with the felspathoid components in perhaps subordinate quantity, yet the analyses may show very high alumina with very little magnesia. An example might be quoted of an analysis of this class published within the last few years:

SiO_2	Fe_2O_3,FeO	Al_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	Ign.
47.83	4.57	30.28	6.72	4.32	trace	1.30	2.19	2.05 = 99.26

In the light of our present knowledge this may almost be said to be an impossible composition for an igneous rock, and it is very clear that a large part of the magnesia must have been thrown down with the alumina. The tendency of alumina to drag down magnesia on precipitation with ammonia is very great and only to be prevented by the presence of a liberal quantity of ammonium salts, and the precipitation should always be repeated, especially where both oxides are present in considerable quantities, under which circumstances even a third precipitation may be necessary. There are many excellent chemists who, from a lack of experience in silicate analysis, fail properly to appreciate this point, and it has been perhaps the most common error in rock analyses.

Returning to our analcite rocks, it is of interest to observe in this connection that leucite and analcite have the same crystal form and the same structural formula except the addition of the molecule of water in the analcite; it is not strange that this difference between them should exist when one reflects how commonly soda salts contain water of crystallization and how much more rarely the potash compounds assume it.

The result of this is then to show why leucitic rocks are commonly effusive ones while the analcitic rocks would be more

commonly intrusive ones, though it is clear special cases might arise where the reverse was the case. Thus Cross[1] is inclined to view the analcite in phonolites described by him as of primary origin and the latest component to form, its formation being due to the local concentration of aqueous vapor produced by its exclusion where crystallization was progressing and by its accumulation in other spots.

The literature contains abundant references to the occurrence of analcite in igneous rocks, but in the great majority of them the rocks described are altered and unlike the beautifully fresh types whose discussion has served for the basis of this article, and it must therefore be uncertain whether the analcite is of primary or secondary origin. In some cases it would appear to be primary, but a discussion of them would carry us too far.

It is now clear (whether one accepts the primary origin of analcite or not) that we must recognize the analcite group of rocks just as we have the leucite group. The analcite basalts corresponding to the leucite basalts are the *Monchiquites* of Rosenbusch, the analcitites or olivine free analcite basalts are the *Fourchites* of J. Francis Williams.[2] The demonstration that the base of the monchiquite group is not glass but analcite does not in any sense impair its distinctness and individuality as a rock group, on the contrary it strengthens it by giving a definiteness of mineral composition that it did not before possess, and at the same time clears up what was one of the most puzzling questions in the petrography of igneous rocks occurring in these small intrusive masses.

And in conclusion we note also that the present case presents another example of how magmas, possessing similar chemical compositions, may form different mineralogical products when crystallizing under different physical conditions.

L. V. Pirsson.

Mineralogical-petrographical Laboratory,
Sheffield Scientific School, Yale University,
New Haven, May 1896.

[1] Geology Cripple Creek, XVI, Ann. Rep. U. S. G. S., Pt. II, p. 36, 1895.
[2] Igneous Rocks, Ark., p. 110, 1890.

THE QUEEN'S RIVER MORAINE IN RHODE ISLAND.[1]

In the autumn of 1894 Mr. F. C. Schrader and the first-named author of this paper, while traversing the western boundary of the Narragansett basin in Rhode Island, as members of Mr. N. S. Shaler's party, came upon an heretofore undescribed frontal moraine of large bowlders in the town of Exeter, R. I. This moraine is locally known in its strongest development on the south side of Shrub Hill on the farm of Mr. N. C. Reynolds as "Cat Rocks," and at another locality not far northward as "The Queen's Kitchen." (See Fig. 1.) Subsequent to this visit, Marbut undertook under the direction of the senior author to trace out this bowlder belt and to determine the indications, if any, of the front of the ice where the bowldery accumulation was feebly developed or wanting. In the following pages, are stated the observations of Woodworth regarding the moraine at Cat Rocks and of Marbut on the extension of the moraine northeastward and southwestward.

The Queen's River bowlder belt is one of a series of well-developed moraines crossing southern Rhode Island. The outermost of these lines, that of Block Island, is imperfectly revealed. The next in succession northward, the Charlestown moraine, skirting the southern coast, is of the knob-and-basin type and is apparently submarginal in its origin. The Queen's River moraine lies at an average distance of twelve miles north of the last named. Investigation has not yet determined whether there is an intermediate moraine or not. All the moraines thus described lie west of a tolerably well marked interlobate axis passing northward from near Point Judith and thus west of East Greenwich toward Woonsocket. East of this line, the ice ran out through the Narragansett Bay depression in

[1] Published by permission of the Director of the United States Geological Survey.

the form of a lobe and west of the line indicated lay a wide but less well defined lobe of the ice-sheet. The general relations of the Queen's River moraine to the frontal deposits known in this field are shown on the accompanying sketch map of Rhode

FIG. 1.—Queen's River Moraine, "Cat Rocks." View looking northeast from a point near the top showing the piling of bowlders successively from the north side.

Island (Fig. 2). The moraine is, in general terms, an upland phase of the sand-plains which mark the frontal stages of the ice-sheet in the Narragansett Bay region. The Queen's River moraine is probably contemporaneous with one of the frontal deposits which occur in the vicinity of Wickford Junction on the east side of the interlobate axis named.

Inasmuch as the bowlder belt at the Cat Rocks locality presents a form of accumulation capable of a somewhat extended diagnosis and furnishes criteria for determining the relations of

the deposit to the ice-sheet, the main features will be discussed somewhat at length.

The bowlder belt lies on the southern slope of Shrub Hill.—The accumulation of bowlders marking this moraine has taken place on the southern slope of a range of low crystalline hills forming the northern side of the river valley. The elevation above the

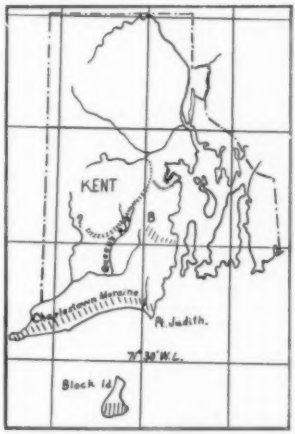

FIG. 2.—Sketch map of Rhode Island showing Queen's River bowlder belt. A, Cat Rocks in Exeter. B, Wickford Junction and Congdon Hill moraine. The small hachures northward indicate frontal deposits near East Greenwich.

stream varies from 20 to 100 feet. At Exeter the line crosses the river. Except for the excessive development of bowlder accumulations along this line, the surface deposits of till both north and south of the belt for several hundred feet would be classed as ground moraine, probably in part englacial till with subglacial material underlying it, the product of the melting out of an indefinite mass of ice.

The occurrence of bowlder belts in Southern New England on the crest of hills or on their southern slopes has been remarked elsewhere, as on Cape Ann by Shaler and Tarr, and on the southern slope of the highlands of Martha's Vine-

yard.[1] There appears to be a causal relation between the local conditions of this position and the deposition of the bowlders from the front of the ice-sheet. A brief analysis of the conditions which may be assumed to arise in such a position is appropriate in this place.

The stand of the ice front at the time of formation of the bowlder belt may be assumed to indicate that for the time being the rate of forward movement of the margin of the ice was equaled by the rate of melting back of the front. There are several reasons for believing that the ice was moving forward at this time. As will be presently explained in detail, the attitudes of some of the bowlders in the moraine at Exeter suggest the application of force in this manner. Had the ice been stagnant, the bowlders distributed in and under it or upon it, would have come to rest as a sheet of discrete bowlders instead of being brought up to a given line and there deposited.

The moraine was formed on that side of the valley which receives the larger amount of insolation. It is to be inferred from this that the same ice front lying upon the southern side of the valley with a less insolation to be reflected against the ice or received upon it would not have melted it back at a rate equal to the forward motion of the front; that the ice would, therefore, have moved over the crest to the next southern slope, where the insolation rate would again equal the forward movement and the ice be brought to a stand. On southern slopes the forward movement of the margin of the ice would be accelerated by gravity, on northward slopes retarded. But the tendency of a northward slope to retard would probably in time be overcome by the push of the ice from behind, while the acceleration on a southward slope would give an actually increased movement. With a balanced ice front on the northern side of the valley, it is therefore probable that the line of halt along the north side of Queen's River Valley indicates a slight advance of the ice front from the country on the north and not an

[1] See forthcoming atlas folio report on surface geology of Martha's Vineyard, by J. B. Woodworth.

immediately preceding retreat from the country lying south of the river.

To this consideration should be added the effect probably arising from the drainage in the valley which would tend to

FIG. 3.—View along the crest of Queen's River moraine showing its massiveness (here about 150 feet wide). The trees are growing from soil accumulated between the more closely set bowlders.

weaken and remove the ice in that position and to increase the frontal melting rate of an ice-sheet advancing into the stream from the north, so that the ice front would from this cause tend to rest along the northern bank. The elevation of the belt above the present stream does not preclude the existence of water at that height in glacial times.

Bowlders are scattered along the front of the belt.—South of the line of piled bowlders is a fringe from one to two rods wide

in which bowlders are scattered as if they had rolled out of a vanished cliff on the north. These fragments vary greatly in size. Their general appearance is shown in Fig. 3, a view taken from the crest of Cat Rocks.

Bowlder Couplets.—Within this fringe and particularly near the line where the materials begin to exhibit superposition, instances may be observed where bowlders occur in pairs: a

FIG. 4.—Bowlder Couplets. A, the stop; B, the stopped bowlder. The arrow indicates the direction of movement.

firmly settled bowlder has one leaning against it on the northern side, as indicated in the accompanying diagram (Fig. 4). These couplets appear best explained by supposing that the leaning bowlder tumbled outward from the ice and was stopped by coming into contact with the block on the south which had preceded it. The association of these colliding couplets with the scattered bowlders above described suggests the probability that the fringe as a whole is due to the falling out of bowlders from the ice front.

The structure of the main wall.—The belt at Cat Rocks is accumulated on a slope, so that while the crest is upwards of thirty feet above the frontal fringe by the roadside on the south, the elevation of the inner mural margin is not more than from three to six feet. The thickness of the belt, however, in places must be from ten to fifteen feet or even more, for the bottoms of the holes between the larger bowlders have not yet been reached with certainty. Many of these spaces are so large as to permit of the entrance of three or four persons with a little inconvenience. The absence of fine materials in the belt is very conspicuous. Although many trees are seen growing up out of the belt, most of them are probably growing out of a soil

which has formed in the lower part of the hollows and not from the soil proper of the surface on which the belt rests. One large oak has grown out of a crevice in a large bowlder, with a result in the end fatal to the tree.

FIG. 5.—View of the Queen's River moraine. "Cat Rocks," from the intra-glacial field north of it, looking at the inner edge of the bowlder wall and showing the line along which the mural (?) front of the glacier stood.

The bowlders in many places along the frontal aspect of the moraine, as shown in Fig. 5, exhibit a mode of piling which seem to the writers accountable only on the supposition of addition from the north. Some of the bowlders may owe their peculiar orientation to a slight forward shoving movement. The general scheme of arrangement is shown in the annexed dia-

gram, Fig. 6, representing the highest part of Cat Rocks. The structure of the bowlder belt at Cat Rocks is, therefore, wholly consistent with the theory of its glacial origin, and the evidence of this exists not only in the main pile but also in the fringe above described.

It would throw some light on the mode of accumulation of these bowlders if it could be determined whether they were

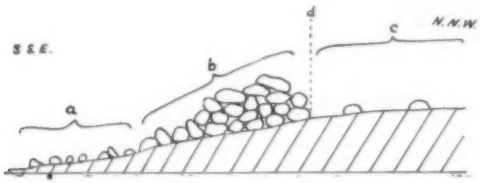

FIG. 6.—Diagrammatic section of highest part of Cat Rocks. A, zone of small scattered bowlders. B, zone of piled bowlders. C, zone of scattered bowlders left by the melting of the ice-sheet. D, position of the ice front.

dropped from an ice cliff as englacial or superglacial matter or were extruded from the base as subglacial débris. It was hoped that we might find criteria in the occurrence of bruised markings due to the violent contact of bowlders which had fallen out in the process of accumulation. The weathering of the blocks, which are largely gneisses and coarse granites, has, however, proceeded so far as to remove the original surface of the rocks where exposed to view, and the points of contact of the larger bowlders are not accessible for examination; so that this point has not been determined.

The northward or inner edge of the belt exhibits a mural contact with the ice front.—No feature in the distribution or accumulation of the bowlders at Cat Rocks is more suggestive of the glacial origin of the accumulation and of the particular relation of the deposit to the ice-sheet than the sharply defined northern wall which is here and there shown. The photograph reproduced in Fig. 5 is a view taken from the intraglacial field about seventy-five feet north of the moraine looking S. S. E. at this mural inner edge where best developed. Nowhere on the

southern side have we seen this phenomenon exactly reproduced. Evidently this mural face indicates the exact front of the ice-sheet at this locality. This wall is then the equivalent of the ice-contact slope at the head or northern side of glacial sand plains and esker-fans. North of this wall lies the intraglacial field, south of it the extraglacial field of that stage of the ice-sheet. It is a line supplying a base of reference from which to work out the relations to the ice-sheet of all associated deposits of the same stage.

North of the bowlder belt, bowlders are scattered as in ordinary ground-moraines.—The bedrock immediately back of the mural inner edge of the moraine is covered by till, the surface of which is pierced by a few scattered bowlders, usually smaller than those in the moraine. Fine materials are in excess. All the indications for hundreds of yards northward indicate a gradual melting down of the ice-sheet or a uniform retreat of the front so as to spread an even coating of till. As to whether the ice disappeared from this particular field by actual retreat of the front or by a general melting down of the whole mass, we have at present no criteria on which to base a decision. There are no indications of distinct submarginal accumulations of the nature of morainal mounds or kame-moraines interior to the frontal bowlder belt. But for the presence of the bowlder belt, one would not, we think, be able to demonstrate the halt of the ice front along this line.

The extraglacial field of the moraine.—South of the belt, there is a gentle slope to the valley of Queen's River, a small stream entering the Pawcatuck. This slope is till-covered to the upper limit of the stratified gravels and sands in the valley. Here and there patches of bowlders occur south of the main belt, in a few places running out like tongues from the moraine, as if along lines of maximum load in the retreating ice.

The outwashed gravels and sands of this stage were not in most of the area built up to the level of the base of the ice on the hillside, so that none of these deposits exhibit sand plains with ice-contact or kame-like slopes on their northern or ice-ward aspect.

Extension northeast of Cat Rocks.—The best development of moraine north of Cat Rocks is at the Queen's Kitchen, about a mile and a half northeast of the village of Exeter. The name is applied to the most northeasterly of a range of three small hills all of which are largely or wholly morainal. They lie on and rise above the surface of a long gentle, southeastwardly sloping plain. North of the moraine the plain is dotted with bowlders and contains many bowlder-filled swamps. South or southeast of the moraine, however, the surface is smoother, the valleys all contain water-laid drift, and bowlders are not so abundant. Bowlders occur occasionally in small patches especially in the heads of shallow valleys though they are of small size.

The moraine stands sharply above this plain, the highest of the three hills rising about sixty feet above the plain at its base. The most southwesterly of the three hills is lower and longer than the others, rising about thirty feet above the surface of the plain on which it stands. It is covered by till carrying a large number of bowlders. No outcrops of country rock were seen though they were not carefully hunted for. The trend of the hill, like that of the range, is about 25° east of north and its length is about 800 feet.

The middle member of the range is a small approximately conical hill about twenty-five feet high and not more than 200 feet in diameter at its base. It is not indicated on the Rhode Island topographic map. It lies about 300 feet north of the last one, and a little way back from a line joining the crests of the other two hills. It contains a larger proportion of bowlders than the last one.

The other member of the range, and the one to which the name Queen's Kitchen is applied, is the highest of the three. It lies about 1200 feet northeast of the crest of the first one described and rises about sixty feet above the plain at its base. Its whole surface is covered with large bowlders with no fine material near the surface. To all appearances the whole hill is merely a pile of bowlders varying considerably in size but all of them large. The northward slope is steep. The bowlders are not scattered out over the plain in this direction so that the

change from the even till plain to the bowlder-covered hill is sudden. The southern slope is more gradual. The bowlders are strung out southeastwardly from the foot of the hill for a distance of several hundred feet. At the foot of the northern slope there is a considerable accumulation of bowlders but they lie just at the foot of the hill and are not scattered out over the plain. They are in just the attitude that they would assume if they had been

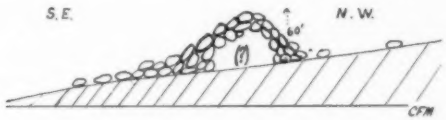

FIG. 7.—Diagram of the Queen's Kitchen phase of the moraine.

piled up against the steep front of the ice and had fallen down when the ice receded.

At Cat Rocks the moraine is accumulated on a locally steeper slope than the general slope of the plain, so that the top of the accumulation rises little if any above the level of the plain on its northern side while at Queen's Kitchen the moraine rises sharply above the plain on all sides. (Fig. 7.)

Between Cat Rocks and the Queen's Kitchen no well-defined bowlder moraine exists. There is, however, a well-defined southern limit in the bowlder-dotted till plain lying north of the supposed position of the ice front. To the south of an irregular line connecting the two localities, the surface drift is water-laid; to the north it is ice-laid. South of this line, bowlders are never seen, excepting scattered ones lying on the higher lands. North of it they are thickly strewn over the surface. It does not appear that the thickly bowlder-covered phase of the till plain extends southward beneath the gravel and sand deposits. South of the northern border of the water-laid drift there are numerous hills which rise well above the level of this deposit, but they carry few bowlders. They all have a smooth outline with only a veneer of drift and the country rock is exposed in many places on them.

North of the Queen's Kitchen there is no prominent bowlder

accumulation along the line of the moraine, though the line limiting the bowlder-dotted till plain on the one hand and the sand and gravel plain on the other is more marked, for a short distance, than it is between Cat Rocks and the Queen's Kitchen.

From the latter place the moraine turns almost due northward and is easily traced for about two miles. It lies along the slope where the higher till-covered plain west of the moraine descends to the lower sand-covered plain east of it. Bowlders are scattered thickly over the slope but they are accumulated very little more along the outer margin than further back. Spurs of the upland, however, which extend out eastward beyond the moraine do not carry many bowlders.

About half a mile south of Frenchtown, the line apparently turns westward along the southern slope of a valley occupied by an eastward flowing stream. An attempt was made to find the moraine north of the valley but it could not be found. The country, as far north as Natick on the Pawtuxet River was searched, but it was not found. The river was followed up to half a mile above Coventry. Here a line of bowlders crosses the river, having a northwesterly trend, but no attempt was made to follow it in either direction.

Extension south of Cat Rocks.—The moraine was traced southwestward from Cat Rocks to within about three miles of Wyoming in the town of Richmond. Over the greater part of the distance it is a fairly-well marked feature, though it never assumes the phase so well developed at Cat Rocks. As a rule, the relations of the morainal and the extramorainal areas are essentially the same as they are north of Cat Rocks. North and northwest of a somewhat irregular line lies a plain of typical bowlder till on which bowlders are most abundant along the southern margin; south and southeast of it lies a region whose valleys are partly filled with water-laid drift, and whose higher lands consist of rounded hills and ridges carrying very few bowlders. The general relief is the same on both sides of the line. The glacial deposits are not thick enough to hide the preglacial topography. The contrast in appearance between the

plains on the two sides of the ice margin is merely one of surface character. One is smooth, the other is bowlder-covered.

From Cat Rocks southwestward for about two miles the southern margin of the till plain is not sharply defined. It graduates southward into the sand and gravel plain, and bowlders are nowhere abundant. This phase is succeeded by a belt extending southwestward to within one and a half miles of Glen Rock village. The southern border of the till plain is characterized by a thick accumulation of bowlders, almost entirely covering the surface, but not piled up into a ridge. The margin lies along the southern slope of a hill, but it lies north of the northern border of the water-laid drift. Occasional patches of bowlders lie between the margin of the bowlder belt and the northern margin of the water-laid drift.

About a mile and a half north of Glen Rock village, the moraine turns westward, crossing Beaver River at Hillsdale. The upland east of Hillsdale is covered with bowlders and the streams are all filled with them. The ponding of the head waters of a small brook which flows into Queen's River at Glen Rock is probably due to morainal accumulations.

Between Hillsdale and the schoolhouse, a mile and a half north of Glen Rock, the moraine is not so well defined as it is further eastward. The bowlders are neither so abundant nor so large. At Hillsdale, however, it again becomes a characteristic bowlder belt. The morainal accumulation consisting mostly of bowlders has ponded the river. The power thus made available was formerly utilized in manufacturing. Down stream from the moraine the valley is filled up to the level of the foot of the moraine with a broad sand plain, but north of it the valley is filled with bowlders. On the slope of the western side of the river valley just back of the village there is an accumulation of very large bowlders, approaching the phase of the moraine developed at Cat Rocks. From this point westward as far as the moraine was traced its development was weak.

J. B. Woodworth.

C. F. Marbut.

STUDIES FOR STUDENTS.

THE PRINCIPLES OF ROCK WEATHERING.

1. Preliminary generalities.
2. Agencies engaged in Promoting Rock weathering.
   - (*a*) Action of the Atmosphere.
   - (*b*) Chemical Action of Water.
   - (*c*) Mechanical Action of Water and of Ice.
3. Analyses of Fresh and Decomposed Rocks.
4. Discussion of Results and Résumé.

(1) PRELIMINARY GENERALITIES.

IN the series of papers to be given under the above title it is proposed to discuss briefly the principles involved in the breaking down of rock-masses when subjected to the ever varying conditions commonly grouped under the name of "weathering."

So striking a phenomenon as the disintegration of a mass of firm rock, naturally did not escape the observation of the earlier workers in geology, and the older literature, from the time of Hutton, bears numerous references to it, though the full significance of atmospheric agencies in bringing about the result, seems not at first to have been fully realized. Indeed the earliest satisfactory accounts to which we have access, are those of writers of the present century, which are based largely upon observations made in moist and warm climates, where the results of such weathering are most apparent.

The exciting cause of this degeneration has been a matter of considerable speculation, and, before proceeding further, it may be well to indicate in brief their tendencies.

Fournet, as quoted elsewhere, writing as early as 1833, insisted upon the efficacy of water containing carbonic acid in

promoting the decomposition of igneous rocks, while Brongniart, writing with particular reference to feldspathic decomposition and the origin of kaolin, laid great stress on the acceleration of the ordinary processes of decay through the electric currents resulting from the contact of heterogeneous rock-masses. Darwin[1] believed the extensive decomposition observed by him in Brazil, to have taken place under the sea, and before the present valleys were excavated. Hartt[2] gave it as his opinion that the decomposition was due to the action of warm rain water soaking through the rock and carrying with it carbonic acid derived not only from the air, but from the vegetation decaying in the soil as well, together with organic acids, nitrate of ammonium, etc. Further that the decomposition had gone on only in regions once covered by forests. Heusser and Claraz,[3] suggest that the decomposition was brought about through the influence of nitric acid. They say "it is without doubt determined by the violence and frequency of the tropical rains, and by the dissolving action of water, which increases with the temperature. It is necessary to observe, moreover, that this water contains some nitric acid, on account of the thunder storms which follow each other with great regularity during many months of the year."

Belt[4] in discussing the extensive decomposition observed by him in Nicaragua says "This decomposition of the rocks near the surface prevails in many parts of tropical America, and is principally, if not always, confined to the forest regions. It has been ascribed, and probably with reason, to the percolation through the rocks, of rain water charged with a little acid, from the decomposing vegetation."

The elder Agassiz[5] laid much stress on the decomposing effects of hot water from rainfall, while Mills[6] attributed no

[1] Geological Observations, p. 417.

[2] Physical Geography and Geology of Brazil.

[3] Ann. des Mines, 5e Series, 17e, 1860.

[4] The Naturalist in Nicaragua. 1874.

[5] Jour. in Brazil, p. 89.

[6] Am. Geologist, June 1889, p. 351.

insignificant amount of the decomposition to the action of carbonic acid produced through the instrumentality of ants.

The chemical changes involved in the process of decomposition received attention from several of the earlier workers, among whom the names of Berthier, J. G. Forschhammer, Brongniart, Gustav Bischof and Ebelmen stand out in greater prominence. More recently the name of Sterry Hunt becomes conspicuous, while the purely geological side of the question has been set forth in numerous papers by De La Beche, L. Agassiz, R. Pumpelly, N. S. Shaler, O. A. Derby, J. C. Branner and others, to whom reference is made in these pages.

(2) THE AGENCIES ENGAGED IN PROMOTING ROCKWEATHERING.

The expression "rockweathering" as commonly used, is a comprehensive term descriptive of the processes which are so constantly engaged in degrading rock-masses and reducing them to the condition of gravel, sand, and clay, and incidentally to soil. These processes are in part physical and in part chemical in their nature; at times simple, and yet again complex. But, whatever the forces engaged, they are, with a few isolated exceptions, superficial — they work from the surface downwards. However much they may have accomplished since the first rock-masses appeared above the primeval ocean, in no case can the actual amount of débris in situ, have formed at one time more than a scarcely appreciable film over the underlying and unchanged material. The decomposing forces early lose their active principles, and become quite inert at depths comparatively insignificant. It is only where through erosion the results of the disintegration are gradually removed, that the processes have gone on to such an extent as to perhaps quite obliterate thousands of feet of massive rock, and furnished the necessary débris for the great thicknesses of sandstone, slate, and shale, which characterize the more modern horizons. In certain isolated cases, it is true, ascending steam and heated waters arising from unknown depths, have been instrumental in promoting decomposition, as is well illustrated in the areas of decomposed

rhyolites in the Yellowstone National Park. Nevertheless, it is to the exceedingly slow process of superficial weathering that we owe a very large share of the apparent rock decomposition and incidental soil formation.[1]

Were it possible it might be well in this discussion to describe each of the involved processes in detail, both in relation to its mode of operation and the results produced. From the fact however, that any one, either physical or chemical, rarely goes on alone, it is thought best to treat the subject as below, and describe in more or less detail the action of (1) the atmosphere, (2) of water in both the solid and liquid form, and (3) that of plant and animal life, finally considering the combined action of all these forces, as manifested on the various types of rock which go to make up the earth's crust.

(*a*) ACTION OF THE ATMOSPHERE.

Pure dry air under constant conditions of heat or cold, can have, but little effect upon rock-masses either in producing physical or chemical changes. Aided, however, by moisture and temperature variations, it becomes a powerful agent for disintegration as well as for transportation.

In its normal state atmospheric air, as is well known, is a mechanical admixture of four volumes of nitrogen to one of

[1] The reader must keep clearly in mind the distinction between the words *alteration* (Ger. Umwandlung), and *decomposition* (Ger. Verwitterung or Zersetzung) as here used. The one is a more or less deep-seated chemical and molecular process through which a rock may undergo a complete change so far as its mineralogical or lithological nature is concerned while yet retaining its geological identity, as where augite becomes altered to uralitic hornblende, or an eruptive olivine rock (peridotite) becomes altered into serpentine. The second is a wholly superficial change brought about through external agencies and resulting in a more or less complete destruction of the original compounds, loss of material and general breaking down of the mass as a geological body, as when granitic rocks decompose to the condition of quartz sand and kaolin, with the separation of free calcium and alkaline carbonates and oxids of iron and manganese. The line of distinction to be sure cannot in nature be always sharply drawn, and indeed alteration is often but a preliminary to decomposition, though this is by no means universally true, as is shown by the superior resisting power of certain trappean rocks in which the pyroxenic and feldspathic constituents have altered into hard, tough aggregates of free quartz, chlorite and epidote.

oxygen, with minute quantities of carbonic acid (from 2.5 to 3.5 parts in 10,000), and in the vicinity of large cities and in volcanic regions, of appreciable quantities of sulphuric and hydrochloric acids as well. With rare exceptions these last may be considered as existing not as free acids, but in combination as sulphates, and chlorides. This, in addition to their limited distribution justifies us in largely ignoring them in the present discussion.

Nitric acid, nitrogen and ammonia.—Much has from time to time been written regarding the occurrence of nitric acid in the atmosphere, and its supposed significance in relation to the subject under discussion. It seems now, however, to be the generally accepted opinion among chemists, that *free* nitric acid in the atmosphere is a thing of comparative rare occurrence and if occurring at all, is present only in very minute quantities. The researches of Boussingault, Cloez, De Luca and others did, it is true, indicate the presence of the acid, but as ammonia is also almost invariably present in amounts sufficient or even in excess of that needed to combine with it as a nitrate, the conclusion seems unavoidable that in the large majority of cases the presence of free nitric acid is impossible, or it exists only momentarily during times of great electrical disturbance (as during thunder showers). As nitrate of ammonia its presence is almost universal. It is probable that neither these gases nor their salts have any direct influence in promoting rock decomposition. It has been demonstrated, however, that nitrogen compounds and nitrogenous matter in the soil, may become subject to nitrification through the action of bacteria, whereby ammonia, nitrous or nitric acid, carbon dioxide and water are formed, though as Wiley says, "The ammonia and nitrous acid may not *appear* in the soils, as the nitric organism attacks the latter at once and converts it into nitric acid."[1] (See further under Influence of Plant and Animal Life.)

In considering the efficacy of these agents as rock destroyers we must not lose sight of the fact that the supply of nitrogen in the soils is as a rule far too small to supply the demands of

[1] WILEY, Principles and Practice of Agricultural Analysis.

growing plants and it is probable that a very large proportion of that which finds its way there, is quickly taken up again by these organisms, and but little is left to promote decay. It is possible that other salts of ammonium than the nitrate may be locally efficacious. Thus M. Beyer as quoted by Van Den Broeck[1] has shown that the feldspars decompose very rapidly under the influence of water containing ammonium sulphate or even sodium chloride, either of which substance may be found in vegetable soil.

Carbonic acid.—The amount of carbonic acid in the air under natural conditions is not a widely variable quantity excepting near volcanoes and the immediate vicinity of gaseous springs. This has been pretty thoroughly demonstrated by Muntz and Aubin.[2] In the vicinity of large cities and manufactories consuming great quantities of coal the amount is naturally increased. Although carbonic acid is the most abundant gas given off by decomposing vegetable matter, it has apparently been definitely ascertained that the amount of this gas in the atmospheres of regions of abundant vegetation is no greater than elsewhere. This has been accounted for on the assumption that the gas as fast as liberated is taken up by growing organisms or carried by rains into the soil. Twenty-one tests of the air in various parts of Boston during the spring of 1870, showed the presence of 385 parts of carbonic acid in 1,000,000.

Eleven tests of the winter air in Cambridge yielded 337 parts in 1,000,000.[3] Dr. J. H. Kidder found the out-door air of Washington to contain 387 to 448 parts in 1,000,000, while Dr. Agnus Smith after an elaborate series of experiments, reported the atmosphere of Manchester (England) as containing 442 parts in 1,000,000.[4] These tests are all of atmospheres in the vicinity of cities. Muntz and Aubin, quoted above, found a

[1] Mem. Sur. Les Phenomes D'Alteration Des Depots Superficial, p. 16.

[2] MUNTZ and AUBIN. Comptes Rendus. 93. 1881, p. 797. Also 96. 1883. pp. 1793–97.

[3] Second Annual Report Massachusetts State Board of Health. 1871.

[4] Air and Rain, p. 52.

general mean of 278 parts in a million for stations in Florida, Mexico, Haiti, Chile and Patagonia, and 296 parts in the north of France. Fischer as quoted by Branner[1] has shown that in rain and snow water the amount of carbonic acid varies between 0.22 per cent. and 0.45 per cent. by volume of water. Assuming that the mean of these figures fairly represent the general average, it is easy, knowing the rainfall of any region to calculate the amount of gas thus annually brought to the surface. Professor Branner has thus calculated that from 3.21 to 11.80 millimeters of carbonic acid gas (CO_2) are annually brought to the surface in certain parts of Brazil. The same method of calculation applied to the various parts of the United States, would give us for the Atlantic coast states $3^{mm}.75$; for the upper Mississippi Valley $2^{mm}.5$; for the Lower Mississippi Valley $4^{mm}.5$, and for the northern Pacific states $6^{mm}.25$. As it is mainly when this carbonic acid is thus brought to the surface by rain and snows that its effects become of direct significance in our present work, we may drop the matter here, to be taken up again when considering the chemical action of water.

Oxygen.—Under ordinary conditions oxygen is the most active principle in the atmosphere, and it is to this agent that we owe the process of oxidation whereby silicates and other minerals containing iron in the protoxide state undergo decomposition. Even here, however, oxidation is almost inactive unless aided by moisture and a further discussion of the subject may well be deferred to be taken up again when discussing the action of water.

Heat and cold.—The ordinarily feeble action of the air is greatly augmented through natural temperature variations. That heat expands and cold contracts is a fact too well known to need elaboration here. That however the constant expansion and contraction due to diurnal temperature variations may be productive of weakness and ultimate disintegration in so inert a body as stone, seems not so generally understood, or is at least less well appreciated, and hence a little space is devoted to the

[1] Bull. Geol. Soc. of Am., Vol. VII, 1896, p. 305.

subject here. Rocks, it must be remembered, as the writer has noted elsewhere,[1] are complex mineral aggregates of low conducting power, each individual constituent of which possesses its own ratio of expansion, or contraction, as the case may be. In crystalline rocks these various constituents are practically in contact. In clastic rocks they are, on the other hand, frequently separated from one another by the interposition of a thin layer of calcareous, ferruginous or siliceous matter which serves as a cement. As temperatures rise, each and every constituent expands and crowds with almost resistless force against its neighbor; as temperatures fall, a corresponding contraction takes place. Since in but few regions are surface temperatures constant for any great period of time, it will be readily perceived that almost the world over there must be continuous movement within the superficial portions of the mass of a rock. The actual amount of expansion and contraction of stone under ordinary temperatures, has been a matter of experiment. W. H. Bartlett[2] has shown that the average rate of expansion for granite amounts to .000004825 inch, per inch of stone, for each degree Fahrenheit; for marble .000005668 inch, and for sandstone .000009532 inch. Adie, in a series of similar experiments found the rate of expansion for granite to be .00000438 inch, and for white marble .00000613 inch.[3]

Shaler states[4] that rock surfaces in the eastern United States may be subjected to temperatures varying from 150° F. at midday in summer, to 0° and below in winter. This change of 150° in a sheet of granite 100 feet in diameter would produce a lateral expansion of 0.8685 inch of surface. That this expansion must tend to lessen the cohesion and tear the upper from the deeper lying layers, is self-evident. As exemplifying this, Professor Shaler states that there are on Cape Ann (Massachusetts) hundreds of acres of bare rock surface completely

[1] Stones for Building and Decoration, WILEY & SONS, New York.

[2] Am. Jour. Science, Vol. XXII, 1832, p. 136.

[3] Trans. Royal Soc. of Edinburgh, XIII, p. 366.

[4] Proc. Boston Soc. Natural History, XII, 1869, p. 292.

covered with blocks of stone which have been separated from the mass beneath by just this process.[1]

It is natural that this form of disintegration should be most pronounced in massive, close-grained rocks. In regions of great extremes of daily temperature, the rupturing of these masses from the parent ledge is frequently attended by gun-like reports sufficiently loud to be heard at a considerable distance. H. von Streeruwitz states[2] that the rocks of the Trans Pecos (Texas) region undergo a very rapid disintegration from diurnal temperture variations, which here amount to from 60° to 75° F. He says, "I frequently observed in summer, as well as in winter time, on the heights of the Quitman Mountains, a peculiar crackling noise, and occasionally loud reports . . . . and careful research revealed the fact that the crackling was caused by the gradual disintegration and separation of scales from the surface of the rock, and the loud reports of crackling and splitting of huge bowlders." The scales thus split off, he says, vary in thickness from one-half to four inches, and their superficial area from a few square inches to many feet. This form of disintegration is necessarily confined to slopes unprotected by vegetation, and is the more pronounced the greater the diurnal vegetation. Dr. Livingston reports that in certain parts of Africa the rock temperatures on the immediate surface rise during the day as high as 137° F., and at night fall so rapidly as to throw off by their contraction sharp angular masses in sizes up to 200 pounds weight. Throughout the desert regions of Lower California, as observed by the writer, the granitic and basic eruptive

[1] The rifting action of heat upon granitic masses is said to have been made a matter of quarry in India. It is stated (*Nature*, January 17, 1895,) that a wood fire built upon the surface of the granite ledge, and pushed slowly forward, causes the stone to rift out in sheets six inches or so in thickness and of almost any desired superficial area. Slabs 60 x 40 feet in area have been thus obtained varying not more than half an inch from a uniform thickness throughout. In one instance mentioned the surface passed over by the line of fires was 460 feet, setting free an area of stone of 740 square feet of an average thickness of five inches. This stone was undoubtedly one of remarkably easy rift, but the case will nevertheless serve our present purposes of illustration.

[2] Fourth Ann. Rep. Geol. Survey of Texas, 1892, p. 144.

rocks, subjected to very little rainfall, and hence almost completely bare of vegetation, have, under the blistering heat of the desert sun, weathered down into dome shaped masses, their débris in the form of angular bits of gravel being strewn over the plain. Particles of this gravel when compared with those which are a product of chemical agencies are found to differ in that each, however friable, is a complex molecule of quartz, feldspar and mica or whatever may be the mineral composition of the rock from which it derived. Aside from a whitening of the feldspathic constituent, due to the reflection of the light from its parted cleavage planes, scarcely any change has taken place, and indeed it more resembles the finely comminuted material from a rock crusher than a product of natural agencies.

Owing however to the low conducting power of rocks, disintegration from this cause alone can go on to any extent only at the immediate surface, and on flat and level planes where the débris is allowed to accumulate must in time completely cease.[1]

It is only on hillsides and slopes or where by the erosive action of running water, or by wind, the débris is gradually removed that such can have any geological significance, although the rate of such disintegration is sufficiently rapid in exposed places to be of serious consequence in stone used for architectural application. (See further under Action of Ice.)

[1] Observations by FORBES (Trans. Royal Society of Edinburgh, Vol. XVI, 1849), showed that at depths of not above twenty-five feet the mean annual temperature was greater than near the surface, these results being confirmatory of those obtained by QUETELET at Brussels. The following tables from FORBES' paper show maximum range of temperatures at varying depths and also the depths at which the annual range is reduced to 0°. 01 centigrade.

I. SHOWING RANGE OF TEMPERATURES FAHR.

Year 1841–1842	Trappean Rock Observatory			Sand Experimental Garden		
Depth	Max.	Min.	Range	Max.	Min.	Range
3 ft	52.85	38.88	13.97	54.50	37.85	17.65
6 "	51.07	40.78	10.29	52.95	39.55	13.40
12 "	49.0	44.2	4.8	50.4	43.5	6.9
24 "	47.5	46.12	1.38	48.1	46.1	2.0

But it is to the action of the air when in motion—to the wind—that is due a very effective part of atmospheric work. Particles of sand drifting along before the wind become themselves agents of abrasion, filing away on every hard object with which they come in contact. As a matter of course this phenomenon is most strikingly active in the arid regions, though the results, when looked for, are by no means wanting in the humid east. It is thought by Professor Egleston that many of the tombstones in the older churchyards of New York City, have become illegible by the wearing action of the dust and sand blown against them from the street. There is among the heterogeneous collections of the National Museum, at Washington, a

Sandstone Craigleigh		
Max.	Min.	Range
53.15	38.25	14.9
51.9	38.95	12.95
50.3	41.6	8.7
48.25	44.35	3.9

II. SHOWING DEPTHS AT WHICH THE ANNUAL RANGE IS REDUCED TO 0°.01 CENT.

Year	Trappean Rock Observatory	Sand Experimental Garden	Sandstone Craigleigh
1837	58.1	72.2	97.3
1838	49.3	61.8	91.0
1839	59.2	63.5	100.0
1840	55.9	67.1	98.8
1841	63.9	68.3	107.4
Mean	57.3	66.6	98.9

Observations on soil temperatures made at the Orono (Maine), Experimental Station, showed the mean daily range of temperatures from April to October, at a depth of 3 inches to be 5°.26; at 6 inches 1°.9; at 9 inches 1°.18; and at 12 inches very slight. At a depth of 1 inch the temperature was lower than that of the air by 2°.4; at 3 inches, by 2°.11; at 6 inches, by 3°.16; at 9 inches, by 3°.94; at 12 inches, by 4°.18; at 24 inches, by 5°.78; and at 36 inches by 7°.10.

The remarkable uniformity of temperatures at comparatively slight depths below the surface is also well illustrated by limestone caverns and in mines. The highest summer temperature of Mammoth Cave being reported as 56° F. and the lowest winter as 52°.5. The mean for the summer being 54° and for the winter 53°.

large sheet of plate glass, once a window in a lighthouse on Cape Cod. During a severe storm of not above forty-eight hours' duration this became on its exposed surface so ground from the impact of grains of sand blown against it, as to be no longer transparent and to necessitate its removal.

Window panes in the dwelling houses of the vicinity are, it is even stated, not infrequently drilled quite through by the same means.

Apply now this agency to a geological field in a dry region. The wind sweeping across a country bare of verdure and parched by drouth, catches up the loose particles of dust and sand and drives them violently into the air in clouds, or sweeps them along more quietly close to the surface where they are at first scarcely noticeable. The impact of a single one of these moving grains on any object with which it may come in contact, is far too small to be appreciable, but the impact of millions acting through days, weeks and years, produces results not merely noticeable but strikingly conspicuous. We have here in fact a natural sand blast, an illustration on a grand scale of a principle in common use in glass cutting and to a small extent in stone cutting also. Constantly filing away on every object with which they come in contact the grains go sweeping on, undermining cliffs, scouring down mountain passes, wearing away the loose bowlders and smoothing out all inequalities. Naturally the abrading action on exposed blocks of stone is most rapid near the ground, as here the flying sand grains are thickest. First the sharp angles and corners are worn away, and the masses gradually become pear shaped, standing on their smaller ends. Finally the base becomes too small for support, the stone topples over, and the process begins anew without a moment's intercession and continues until the entire mass disappears—becomes itself converted into loose sand drifted by the wind and an agent for destruction. W. P. Blake was the first, I believe, to call public attention to this phenomenon, having observed it while in the pass of San Bernardino (California) in 1853. G. K. Gilbert has also published some interesting facts as noted by him-

self while geologist of the Wheeler Expedition west of the 100th meridian in 1878. In acting on the hard rocks the sand cuts so slowly as at times to produce only grooved or fantastically carved surfaces often with a very high polish. The geologists of the 40th Parallel Survey in 1878 described like interesting phenomena as observed on the western faces of conglomerate bowlders exposed to the sand blasts of the desert regions of Nevada. The surface of the otherwise light colored rock was found to have assumed a dark lead gray hue and a polish equal to that of glass, while the sand had drilled irregular holes and grooves, often three-fourths of an inch deep and not more than an eighth of an inch in diameter, through pebbles and matrix alike.

Even the humid east is not without its illustrations of natural sand-blast carvings. On the shores of Cape Elizabeth, Maine, the cliffs facing toward the open sea are often riddled with peculiarly irregular holes formed by the gyrations of sand grains blown up from the beach below and kept spasmodically in motion by the wind.

(*b*) CHEMICAL ACTION OF WATER.

Pure water, although an almost universal solvent, nevertheless acts with such slowness upon the ordinary materials of the earth's crust that its results are scarcely appreciable to the ordinary observer. It by no means follows, however, that its effects are not worthy of our consideration here. This is particularly true when we reflect that the results we are discussing are not merely those of days and weeks, but of years even when counted by the tens of thousands and millions. Moreover absolutely pure water, as a constituent of our earth and its atmosphere, presumably does not exist. We have to consider its action as well when contaminated with sundry salts and acids which it almost universally holds, having taken them up in passing through the atmosphere and in filtering through the overlying layer of organic matter and decomposition products which cover so large a portion of the surface of the land. It is when thus contaminated, then, that are manifested the wonder-

ful solvent and other chemical reactions which have been instrumental in promoting rock destruction, and it is here, then, that we will consider the complex chemical processes commonly grouped under the head of oxidation, deoxidation, hydration, and solution.

Oxidation.— Oxidation is perceptibly manifested only in rocks carrying iron either as sulphide, protoxide carbonate, or silicate. The sulphides, in presence of water and when not fully protected from atmospheric influences, readily succumb, producing sulphates, which being soluble are rapidly removed in solution, or hydrated oxides, sulphuretted hydrogen, and perhaps free sulphur. Such an oxidation is attended by an increase in bulk so that if nothing escapes by solution there may be brought to bear a physical agency to aid in disintegration. Weathered rocks containing iron sulphides may not infrequently be found with cubical cavities quite empty or partially filled with the brownish, yellow, or red product of their oxidation, in a more or less powdery condition. Pyrites, though a widespread constituent, is nevertheless a less conspicuous agent in promoting rock decomposition than the protoxide carbonates and silicates. In these the iron passes also over to the hydrated sesquioxide state, as is indicated by the general discoloration whereby the rock becomes first streaked and stained and finally uniformly ochreous. The more common minerals thus attacked are the ferruginous carbonates of lime and magnesia and silicates of the mica, amphibole, and pyroxene groups. As the oxidation progresses the minerals become gradually decomposed and fall away into unrecognizable forms. The red and yellow colors of soils are due invariably to the iron oxides contained by them.

Deoxidation is a less common feature than oxidation. Water carrying quantities of organic acids may, through their influence, take away a portion of the combined oxygen of a sesquioxide, converting it once more into the protoxide state, in which form it may be dissolved and removed as a ferrous carbonate or sulphate. The local bleaching of certain ferruginous

sands and sandstones is due to this action. Through a similar process of deoxidation ferrous sulphates may be converted into sulphides, a process which undoubtedly takes place in marine muds protected by the water from atmospheric action. *Hydration*—the assumption of water—more commonly accompanies oxidation, and indeed is an almost constant accompaniment of rock decomposition, as may be observed in comparing the total percentages of water in fresh and decomposed minerals and rocks, as given in any series of analyses. The amount of water thus taken up is in some cases surprisingly large. This assumption, provided it be not accompanied with an equal loss of other constituents, is attended with an increase in bulk such as may be quite appreciable. In cases where rock disintegration progresses without serious decomposition or surface erosion a corresponding expansion must also take place. The Comte de la Hure, as quoted by Branner,[1] has expressed the opinion that some of the hills of Brazil have actually increased in height through this means. The present writer has calculated that the transition of the granitic rock of the District of Columbia into arable soil must be attended by an increase in bulk amounting to 88 per cent.

Hydration as a factor in rock disintegration is, in the writer's opinion, of more importance than is ordinarily supposed. Granitic rocks in the District of Columbia have been shown[2] to have become disintegrated for a depth of many feet with loss of but some 13.46 per cent. of their chemical constituents and with apparently but little change in their form of combination. Aside from its state of disintegration the newly-formed soil differs from the massive rock mainly in that its feldspathic and other silicate constituents have undergone a certain amount of hydration. Natural joint blocks of the rock brought up from shafts excavated during the extension of the city waterworks were, on casual inspection, sound and fresh. It was noted, however, that on exposure to the atmosphere such

[1] Bull. Geol. Soc. of America, Vol. VII, 1896, p. 284.

[2] MERRILL, Bull. Geol. Soc. of America, Vol. VI, p. 341, and Vol. VII, p. 357.

not infrequently shortly fell away to the condition of sand. Closer inspection revealed the fact that the blocks, when brought to the surface, were in a hydrated condition, giving forth a dull instead of clear, ringing sound when struck with a hammer, and showing a lusterless fracture, though otherwise unchanged. That such had not previously fallen away to the condition of sand, it is assumed, was due to the vise-like grasp of the surrounding rock-masses.

Solution.—It is, however, the solvent power of water that most concerns us here, though solution alone plays a comparatively unimportant part upon rocks not first subjected to physical and oxidizing agencies, excepting in the case of those composed essentially of carbonate of lime or magnesia. Rain and nearly all superficial waters as already noted contain traces of carbonic and other organic acids,[1] which act upon the material of the rocks, carrying it away invisibly, but none the less surely.

As long ago as 1848 the Rogers brothers showed[2] that pure water partially decomposed nearly all the ordinary silicate minerals which form any appreciable part of our rocks. The action of carbonated water upon the minerals in a finely pulverized condition was recognizable in less than ten minutes, but pure water required a much longer time before its effect was sufficient for a qualitative determination. So pronounced was the action

[1] Under this head are included the complex, unstable and little understood products of plant decomposition known as humic, ulmic, crenic and apocrenic acids. These act not merely as reducing agents (from their tendency to themselves undergo oxidation) but are energetic solvents as well, attacking not merely the lime carbonates but also silica and phosphates, arsenates and sulphates of the alkaline earths and the metallic sulphides.

BERTHELOT and ANDRE (Comptes Rendus Academie de Paris, 114, 1892, pp. 41–43) have shown that the brown substance of humus and analogous compounds undergo direct oxidation under the influence of the air and sunlight, forming carbonic acid. These reactions are purely chemical, taking place without the intervention of microbes, and are accompanied by a change in color of the original humus. The oxidation is rendered more active through the division and mellowing of the humus by cultivation. Through chemical union of the carbonic acid with certain bases, as lime soda and potash there are formed soluble carbonates which may be leached out by meteoric waters.

[2] American Journal of Science, Vol. V, 1848.

that the presence of the alkalies of lime and magnesia could be recognized in a single drop of the filtrate from the liquid in which the powdered minerals were digested. By digestion for forty-eight hours in carbonated waters they obtained from hornblende, actinolite, epidote, chlorite, serpentine, feldspar, etc., a quantity of lime, magnesia, oxide of iron, alumina, silica and alkalies amounting to from 0.4 to 1 per cent. of the whole mass. The lime, magnesia and alkalies were obtained in the form of carbonates; the iron, in the case of hornblende, epidote, etc., passing from the state of carbonate to that of peroxide during the evaporation of the solutions. Forty grains of finely pulverized hornblende, digested for 48 hours in carbonated water at a temperature of 60°, with repeated agitation yielded: silica 0.08 per cent.; oxide of iron 0.095 per cent.; lime 0.13 per cent.; and magnesia 0.095 per cent. with traces of manganese. Commenting on these results Bischof remarks[1] that "by repeating this treatment 112 times with fresh carbonated water, a perfect solution might be affected in 224 days." If now he says, "40 grains of hornblende unpowdered, in which, according to the above assumption, the surface is only $\frac{1}{1000000}$ of the powdered, were treated in the same way, and the water renewed every two days, the time required for perfect solution would be somewhat more than six million years." In considering these figures and their practical bearing we must remember that while in nature the quantity of water coming in contact with a crystal imbedded in a rock during a given time is much less than that assumed above, the mineral is undergoing a gradual splitting up, becoming more and more porous, so that the process is gradually accelerated.

Richard Müller has also shown[2] that carbonic acid waters will act even during so brief a period as seven weeks upon the silicate minerals with such energy as to permit a quantitative determination of the dissolved materials. The accompanying

[1] Chemical and Physical Geology, Vol. I, p. 61.

[2] Untersuchen über die Einwirkung des kohlensaurehaltigen wasser auf einige Mineralien und Gesteine. Tschermaks Min. Mittheilungen. 1877, p. 25.

table shows (1) the percentages of the various constituents thus taken out by the carbonated water and (2) the total percentages of the materials dissolved. That is to say, the figures 0.1552 given for adular under SiO_2, indicate that 0.1552 per cent. of the total 65.24 per cent. of the silica contained by the mineral has been removed, and so on. The last column, on the other hand, gives the total per cent. of the entire rock of all the constituents extracted.

Mineral	SiO_2	Al_2O_3	K_2O	Na_2O	MgO	CaO	P_2O_5	FeO	Total
Adular.....	0.1552	0.1368	....	....	.. .	....	....	trace	0.328
Oligoclase...	0.237	9.1713	....	2.367	....	3.213	....	"	0.533
Hornblende .	0.419	trace	....	....	....	8.528	....	4.829	1.536
Magnetite ...	trace	.....	....	....	....	....	....	0.942	0.307
Apatite	.....	.....	....	....	....	2.168	1.822	.....	2.018
Olivine	0.873	trace	....	....	1.291	trace	....	8.733	2.111
Serpentine ..	0.354	.....	....	....	2.649	....	....	1.527	1.211

The summary of his investigation is given as below:

(1) All the minerals tested were acted upon by the carbonated water.

(2) In this process there were formed carbonates of lime, iron, manganese, cobalt, nickel, potash and soda.

(3) In the action of the carbonated waters upon the alkaline silicates like the feldspars, a small amount of silica went always into solution, presumably in the form of hydrate.

(4) Even alumina was dissolved in appreciable quantities.

(5) Adular proved more resisting to the action of the acid than did oligoclase.

(6) The first stage of decomposition in the feldspars was a reddening process; the second, kaolinization.

(7) Hornblende was more easily decomposed than feldspar.

(8) Increase of pressure on the solution was productive of more energetic action than prolonging the time.

(9) Of all the minerals tested, the magnetic iron was least affected.

(10) Apatite was readily acted upon, as could be detected by its appearance under the microscope.

(11) Olivine was the most readily attacked of all the silicates tested, probably twice as easily decomposed as the serpentine.

(12) Magnesian silicates were attacked by the carbonated waters. Hence serpentine cannot be considered a final product of decomposition.[1]

Of all the materials forming any essential part of the earth's crust the limestones are most effected by the solvent power of water. It is stated that pure water will dissolve one part in 10,800 when cold and one part in 8.875 when boiling of lime carbonate.

Since rock weathering is, as already stated, a superficial phenomenon, we have to do only with waters of ordinary temperatures and under ordinary conditions of pressure though this expression must not be taken as necessarily meaning *cold* waters, since during the rainy season in tropical countries the waters falling upon the heated rocks may have their temperatures raised as high as 140° F. or even 150° according to A. Caldeleugh.[2]

It is almost wholly to this solvent action that is due the formation of the multitudinous caverns of limestone regions. Even where caverns are not apparent the corrosive action is evident to the practiced eye. In the quarry regions of Tennessee surface blocks of limestone are often grooved to a depth of an inch or more with wonderful sharpness, simply from the water of rainfalls with its acids absorbed from the atmosphere and surface soils, while in the quarry bed the stone is found no longer in continuous layers, but in disconnected bowlder-like masses. In such cases casual examinations give very little clue to the rapidity of the destruction going steadily on, since all is removed in solution excepting the comparatively small amount

[1] Serpentine, however, cannot be properly considered a decomposition product. It is rather a product of *alteration*.

[2] On the Geology of Rio Janeiro, Trans. Geol. Soc. of London, 2d Ser. Vol. II, 1829.

of insoluble matter (usually clay or silica) existing as an impurity. In these limestone regions the solvent action has not infrequently gone on so extensively as to leave its imprint upon the topographic features of the landscape. The drainage is no longer wholly superficial but by subterranean streams sinking entirely into the ground to reappear again at lower levels, it may be miles away, having traversed the intervening distance in some of the numerous passages (fissures enlarged by solution) with which the rocks abound. Entire landscapes are not infrequently undulating through the abundance of sinkholes — shallow depressions down through which the water has percolated and escaped into the underground passages. An idea of the amount of material thus dissolved may be gained when I state that some 275 tons have been calculated[1] as annually removed from each square mile of Calciferous (Lower Silurian) limestone exposed in the Appalachian region alone, while a well-known English authority[2] has calculated that with an annual rainfall of 32 inches percolating only to a depth of 18.3 inches, there are annually removed by solution from the superficial portions of England and Wales an average of 143.5 tons per square mile of area. He further calculates that the average amount of carbonate of lime alone annually removed from each square mile of the entire globe amounts to 50 tons. It is to this corrosive action of meteoric waters that still another authority[3] would attribute the slight thickness and nodular condition of many beds of Palæozoic limestone. He argues that originally thick bedded limestones have, during the ages subsequent to their formation and uplifting become so impoverished through the dissolving out and carrying away in solution of the lime carbonate, as to have been quite obliterated or reduced to mere nodular bands, and given rise to important palæontological breaks in the geological record. Other than organic acids may locally exert a potent influence.

[1] A. L. EWING, Am. Jour. of Science, 1885, p. 29.

[2] T. MELLARD READE (Chemical Denundation in Relation to Geological Time).

[3] F. RUTLEY, the Dwindling and Disappearance of Limestones, Quar. Jour. Geol. Soc. of London, Aug. 1893.

Thus Robert Bell has described the dolomitic limestones underlying the waters along Grand Manitou Island, the Indian peninsula and adjacent portions of Lake Huron and the Georgian Bay, as pitted and honeycombed in a very peculiar and striking manner. This corrosion, it is believed is, produced through the solvent action of sulphuric acid in the water, the acid itself arising from the decomposition of the sulphides of iron pyrites and pyrrhotite, which exist in great quantities in the Huronian rocks to the northward.[1]

GEORGE P. MERRILL.

[1] Bull. Geol. Soc. of America, Vol. VI, p. 47-304.

(To be continued.)

EDITORIAL.

THAT law of rhythm which pervades the inanimate world seems also to preside over the incoming and outgoing of intellectual stages and commanding personalities. Just prior to the middle of this century there arose a group of geologists of peculiar ability, and for five decades or more they have wielded a most powerful influence in reshaping the doctrines of the science which had been transmitted in relative immaturity from the earlier fathers. For the past two decades they have taken the place of these older masters as the recognized fathers of geology. But we are now called upon to note that the ebb of the rhythm, happily so long delayed, has of late been setting sadly out. The inevitable evening tide of life that so lately bore Dana away has, within the past four months, carried away Daubrée, Pestwich, Whitney and Green, all eminent, if not pre-eminent, in their special fields. The first three had filled out more than the usual span of active life, eighty-two, eighty-four and seventy-six years respectively, while the last had reached the ripe maturity of sixty-four years. Daubrée was best known for his "*Études Synthétique de Géologie Expérimentale;*" Prestwich for his "*Geology, Chemical, Physical and Stratigraphical;*" Whitney for his "*Metallic Wealth of the United States,*" and Green for his "*Physical Geology;*" though these are but the more conspicuous among their many important treatises. Works and names like these give deep inspiration to those whose careers are yet opening before them, and upon whom it falls to swell the incoming tide that must replace, so far as it may, the outgoing one.

T. C. C.

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A UNIQUE feature of the meeting of the geological section of the American Association for the Advancement of Science was

the commemoration of the sixtieth anniversary of the great work of Professor Hall on the geology and palæontology of the state of New York. Six decades of continuous service, and that, *nota bene*, official service, with a hopeful outlook on the seventh, is indeed a rare record. No work has been equally influential in the correlation of the palæozoic terranes of America, and none is more worthy of the special honors so appropriately and so happily bestowed.

The synopsis of the papers given in *Science* indicates a programme of much variety and value. The scientific interest seems to have reached its climax in the discussions of Mr. Gilbert bearing upon the history of Niagara Falls, and in the excursion connected therewith. The announcement of a third postglacial outlet for the upper lakes is a matter of wide historical importance. The following is a list of the papers offered:

"Notes on the Artesian Well sunk at Key West, Florida, in 1895." By Edmund Otis Hovey.

"The Hydraulic Gradient of the Main Artesian Basin of the Northwest." By J. E. Todd.

"The True Tuff-beds of the Trias, and the mud enclosures, the underrolling, and the basic pitchstone of the Triassic Traps." By B. K. Emerson.

"Volcanic Ash from the North Shore of Lake Superior." By N. H. Winchell and U. S. Grant.

"The 'Augen-gneiss,' Pegmatite Veins, and Diorite Dikes at Bedford, Westchester Co., N. Y." By Lea McI. Luquer and Heinrich Ries.

"The Tyringham (Mass.) 'Mortise Rock,' and Pseudomorphs of Quartz after Albite." By B. K. Emerson.

"The Succession of the Fossil Faunas in the Hamilton group at Eighteen Mile Creek, N. Y." By Amadeus W. Grabau.

"Development of the Physiography of California; Synopsis of California Stratigraphy." By James Perrin Smith.

"Ancient and Modern Sharks, and the Evolution of the Class." By E. W. Claypole.

"Observations on the Dorsal Shields in the Dinichthyids." By Charles R. Eastman.

"The Discovery of a new Fish Fauna, from the Devonian Rocks of Western New York." By F. K. Mixer.

"Notes on certain Fossil Plants from the Carboniferous of Iowa." By Thomas H. Macbride.

"Interglacial change of course, with gorge erosion, of the St. Croix River, in Minnesota and Wisconsin; The Cuyahoga Preglacial Gorge in Cleveland, Ohio." By Warren Upham.

"A Revision of the Moraines of Minnesota." By J. E. Todd.

"Origin of the High Terrace Deposits of the Monongahela River." By I. C. White.

"The Making of Mammoth Cave." By Horace C. Hovey.

"The Colossal Cavern." By Horace C. Hovey.

"James Hall, Founder of American Stratigraphic Geology." By W J. McGee.

"Professor Hall and the Survey of the Fourth District." By John M. Clarke.

"Sheetflood Erosion." By W J McGee.

"Glacial Flood Deposits in the Chenango Valley." By Albert P. Brigham.

"Origin of Conglomerates." By T. C. Hopkins.

"Origin of Topographic Features in North Carolina." By Collier Cobb.

"The Cretaceous Clay Marl Exposure at Cliffwood, N. J." By Arthur Hollick.

"Post-Cretaceous Grade-Plains in Southern New England." By F. P. Gulliver.

"The Algonquin River." By G. K. Gilbert.

"The Whirlpool-Saint David's Channel." By G. K. Gilbert.

"Profile of the bed of the Niagara in its Gorge." By G. K. Gilbert.

"The Niagara Falls Gorge." By George W. Holley.

"Origin and Age of the Laurentian Lakes and of Niagara Falls." By Warren Upham.

"Correlation of Warren Beaches with Moraines and Outlets in Southeastern Michigan." By F. B. Taylor.

"Notes on the Glacial Succession in Eastern Michigan." By F. B. Taylor.

"The Operations of the Geological Survey of the State of New York." By James Hall.

"The Eocene Stages of Georgia." By Gilbert D. Harris.

"The Origin and Age of the Gypsum Deposits of Kansas." By G. P. Grimsley.

"Geomorphic Notes on Norway." By J. W. Spencer.

"The Slopes of the Drowned Antillean Valleys." By J. W. Spencer.

"Notes on Kansan Drift in Pennsylvania." By E. H. Williams.

"Preliminary Notes on the Columbian Deposits of the Susquehanna." By H. B. Bashore.

"Pre-Cambrian Base-leveling in the Northwestern States." By C. W. Hall.

THE monograph on the North American Camerata by Wachsmuth and Springer, which was reviewed by Charles R. Keyes in the February-March number of the JOURNAL, has not yet been issued and we are informed that it will not probably appear before the close of the year. It is perhaps unnecessary to say that the review was accepted without so much as a question as to the fact of the issuance of the work, and we are assured by the reviewer that he had no doubt, from his understanding with the lamented senior author, of its appearance before the publication of the review. Our common apologies are due for the premature notice, which are only relieved by the reflection that the review was an expression of warm admiration of the work and of a desire to give it a prompt and most cordial recognition. It is due to Mr. Bather, the eminent English student of the Crinoidea, to whose views adverse illusion was made on a certain point, to ask a suspension of judgment on the matter in question until the work shall be read. T. C. C.

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The current season is proving exceptionally fruitful in Arctic exploration. The results of Nansen's most remarkable voyage have much scientific significance, especially his discovery of a deep sea stretching as far east as 133° longitude and as far south as 78° latitude. This, with its attendant phenomena, forms a very important contribution to the general configuration of the crust in the north polar region. Nansen has our warmest felicitations, as he has had all along our fullest sympathy.

The safe return of the gallant Peary with the scientific parties from Cornell University and the Massachusetts Institute of Technology is also a matter of congratulation. Although unsuccessful in bringing away the great meteorite, they have undoubtedly gathered much valuable data regarding the ethnology and geology of North Greenland. The results of the glacial studies and of the pendulum observations will be awaited with special interest. T. C. C.

Reviews.

Great Valley of California; a Criticism of the Theory of Isostasy, by F. Leslie Ransome: Univ. California, Bull. Geol. Dept., Vol. I, pp. 371–428, 1896.

British Geology, by T. Mellard Reade: Geological Magazine, Dec. 4, Vol. II, pp. 557–565, 1895.

Notes on the Gravity Determinations Reported by Mr. G. R. Putnam, by Grove Karl Gilbert: Bull. Philos. Soc. Washington, Vol. XIII, pp. 61–76, 1895.

Three papers have been issued recently which have a direct bearing upon the theory of isostasy. Two are of the nature of criticisms; one being the outcome of studies conducted in this country, and the other of inquiries instituted in England. The third introduces some new complications which the advocates of the hypothesis would hardly expect.

The first memoir is of more than ordinary interest in being an attempt to practically test the theory from a purely geological standpoint, and to apply the principles to a particular limited region unusually favorably situated for obtaining tangible results. The paper had its origin in a review of the literature bearing upon the theory of "conservation of equilibrium in the earth's external form, which Dutton has named Isostasy, and which has come into prominence mainly through the labors of that illustrious group of American geologists to whom geology is so deeply indebted for certain broad views and far-sighted generalizations, which in spirit and expression recall the wide regions and clear atmosphere in which the authors worked."

Accordingly the discussion is appropriately subdivided into five distinct parts, (1) a description of the Great Valley as it is today, (2) an outline of the geological evolution through which it has arrived at its present form, (3) an account of the development of the so-called "doctrine of isostasy" as a working hypothesis, (4) a discussion of the applicability of this hypothesis to the Great Valley, and (5) a more

general discussion of the theory of isostasy, with illustrations drawn from other regions of elevation or subsidence.

Before all, the physiographic features of the Great Valley are fully considered and the several parts in some detail. The main geological features are described and the evidence of several deep wells is brought in to show the composition of the strata underlying the region.

The geological history of the region is briefly and concisely related. This leads directly to the main theme—the principles of isostasy, for the Great Valley has an area in which there has been profound and progressive subsidence accompanied by great deposition. The literature relating to the theory is compactly brought together and summarized. The theory is then examined in the light of the facts derived from a study of the particular area.

The Great Valley represents a limited area in which 2000 feet of sediments were deposited at the same time that the rim was being raised. In explanation of the attendant phenomena the hypothesis of isostasy is not only regarded as unnecessary, but the facts presented are thought to directly oppose the idea of isostatic subsidence. A consideration of the essential features of isostasy shows it to be merely an hypothesis of readjustment and not of initial movement. It can operate only after conditions have become unstable. So far as applied to the Great Valley it is shown conclusively that the orogenic movements elevating the Coast Range began before the "formation of the valley and are consequently independent of any loading and subsidence." A little latter the Sierra Nevada range began to rise and in the great syncline between were deposited shallow water sediments to a depth of 2000 feet. Other facts are enumerated that are believed to be opposed to the hypothesis of isostatic movement in the valley. Several Californian areas are also brought in as presenting phenomena perfectly inexplicable upon the isostatic principle. After passing them the general discussion of the theory as a whole is reached.

In discussing the data upon which the theory has been made to rest specific cases are taken up. McGee's consideration of the Gulf of Mexico and the great Mississippi embayment receive particular attention. It is not, however, with the acumen shown in the other parts of the memoir. Some of the very objections urged against the region having subsided by loading are themselves so manifestly defective that they have the very opposite effect from that intended and naturally strengthen the hypothesis rather than weaken it. One point in partic-

ular may be noted: "The Mississippi River, during later geological times, has pushed its delta from Cairo out to its present termination in the Gulf of Mexico, an extension that is not compatible with the idea of *pari passu* local sinking under load, but which indicates a subsidence of more general extent, and independent of such local loading, inasmuch as the maximum effect has been, not near Cairo, at the original point of loading, but to the south of it—probably in the deep hollows of the present Gulf of Mexico. The river did not stop to build up a thick mass of delta accumulations at Cairo, as it should have done according to the theory of isostasy; but, attracted onward by the independent subsidence to the south it has covered the floor of the valley with relatively thin deposits only, and advanced persistently out into the Gulf."

Now the real reason that the Mississippi River did not build up a thick mass of delta accumulations at the head of the present embayment, "as it should have done according to the theory of isostasy" is that Cairo is probably not only not "the original point of loading," but the latter point is to the south of it, far to the south, in fact nearly as far as New Orleans. This is at once apparent from a glance at the history of the region. At the close of the Cretaceous or early in the Tertiary the whole region was a vast graded surface, or peneplain, the southern limit of which was as far south at least as central Louisiana. The present Mississippi River was a comparative insignificant stream with none of its present tributaries beyond the present city of St. Louis. The peneplain is found on the east side of the embayment dipping westward and on the west side dipping eastward under the unconsolidated clastics of the embayment, thus forming a broad shallow syncline, as recently shown by Griswold. The warping which has taken place since the beginning of this down-sinking along the line of the Mississippi has allowed a relatively thin mantle of later sediments to be deposited over a large area. While at various times the waters of a shallow sea may have been extended over a considerable portion of the embayment "the original point of loading" was doubtless not so very far from where it should be, nor is the present point of maximum depression and maximum loading far from "where it should be according to the theory of isostasy." This, it may be added introduces factors that are not commonly taken into account in the consideration of the genesis of large deltas.

Most of the other objections to the hypothesis of isostasy are well formulated and some of them appear unsurmountable.

In conclusion the author says: "The considerations presented in the foregoing paper indicate that, while the greater inequalities of the earth's surface, such as the continental arches and the oceanic depressions, may exist by reason of isostasy, the mass of available evidence is opposed to the view that denudation and sedimentation are able to produce movements in the earth's crust, as direct consequences of the weight of the material shifted. Not only do such superficial processes seem inadequate to initiate deep-seated crustal movements, but, as far as we can see, the movements, even when initiated through other causes, are as indifferent to such processes as is a slumbering volcano to the changes wrought by human tillage upon its flanks."

Mr. Reade's most recent references to the hypothesis of isostasy are contained in the presidential address to the Liverpool Geological Society in which he describes briefly the geology of the British Isles in relation to mountain building. The allusions to isostasy are incidental rather than specific and the conclusions to be deduced are against the theory. In this connection he gives a summary of his latest opinions regarding the cause of orogenic movements and ascribes them entirely to changes of temperature, producing expansion and contraction, and not to the shrinkage of the nucleus of the earth, the closing in of the non-shrinking crust upon it and the consequent folding by tangential pressure. In concluding he says: that "Neither does the principle of isostasy so insisted upon by American geologists explain the compression, folding and building up of great masses of sediment into mountain ranges. On the principle of isostasy, it must be obvious to anyone possessing even a rudimentary acquaintance with mechanics that the sinking of the bed of the seas on which great deposits are accumulating, and to some extent a rise of surrounding land, may be explained, but not the lateral compression and elevation of the sediments themselves into mountain ranges."

Mr. Gilbert's notes are of great interest at this time. They are based upon a series of trans-continental gravity determinations made by Mr. G. R. Putnam, and are appended to the latter's article. As generally understood isostasy is intended to cover those oscillations which are the direct result of local or provincial loading and unloading. This appears to be the specific limitation placed upon the hypothesis by Messrs. Dutton and McGee. Mr. Gilbert, however, uses the term

in the present case in the broadest sense. He starts out by postulating general isostasy thus making the term nearly equivalent to a universal static conservation. His theme is stated as follows: "Let us postulate that the greatest features of the earth's relief, such as continents and great plateaus, are sustained isostatically, and that the small features, such as hills and small mountains, are within the competence of terrestrial rigidity, and then let us inquire what the pendulum work of the Coast Survey has to tell of the status of features of intermediate size, namely the greater mountains and smaller plateaus."

After describing the methods followed in making the determinations the details of the various stations at which pendulum measurements were made are discussed. Although the results of the calculations deviate greatly from what would be expected according to the hypothesis of isostasy the measurements are found to be "six times as discordant from the point of view of rigidity as they are from the point of view of isostasy."

In conclusion it is stated that the "measurements of gravity appear far more harmonious when the method of reduction postulates isostasy than when it postulates high rigidity. Nearly all the local peculiarities of gravity admit of simple and rational explanation on the theory that the continent as a whole is approximately isostatic, and that the interior plain is almost perfectly isostatic. Most of the deviations from the normal arise from excess of matter and are associated with uplift. The Appalachian and Rocky Mountains and the Wasatch plateau all appear to be of the nature of added loads, the whole mass above the neighboring plains being rigidly upheld. The Colorado plateau province seems to have an excess of matter, and the Desert Range province may also be overloaded. The fact that the six stations from Pike's Peak to Salt Lake City, covering a distance of 375 miles, show an average excess of 1345 rock-feet indicates greater sustaining power than is ordinarily ascribed to the lithosphere by the advocates of isostasy." CHARLES R. KEYES.

Text-Book of Palæontology. Vol. I., Part 1. By KARL A. VON ZITTEL. Translated and edited by CHARLES R. EASTMAN, PH.D. London: Macmillan & Co., Ltd., 1896.

An English edition of von Zittel's *Palæontologie* is the most welcome of palæontological works that has appeared in a long time. The

original edition while largely used in this country did not, on account of being in a foreign language, meet all the wants of American students, particularly the younger ones. No department of science has been more in need of a good English text-book than palæontology. Educators in general will owe to Dr. Eastman a deep debt of gratitude for providing our colleges and higher schools with a "translated, revised and enlarged edition" of the best manual on palæontology that has ever been written. Professor von Zittel is to be congratulated not only for the improvement presented by his new text-book, but also, as shown by the results, for having entrusted the preparation of the translated edition to such excellent hands.

To one accustomed only to the standard English works on palæontology, or even to the majority of foreign ones, the style and mode of treatment adopted by the author must seem a welcome innovation. The plan on which it is written is in fact original with Professor von Zittel, and was first adopted by him in the larger work, for which he is famous, the *Handbuch der Paläontologie*. It may be regarded as the best method yet devised for treating, in one and the same book, not only the main facts of the science as viewed from the biological side, but also systematic palæontology. Authors of zoölogical text-books are confronted with the same difficulty, how to relegate to the systematic and the general part each its due share of attention, without confusing the student nor presupposing for him too much technical knowledge. The great success of von Zittel's method has been demonstrated during the twenty years his larger treatise has been in use, and justifies its extension to an elementary work.

Another feature which the present text-book shares in common with the *Handbuch* is its richness of illustration. Its figures are necessary to the advanced student, and everyone knows for himself how dependent he is on good figures for an understanding of new forms; how much more essential is it that the beginner be supplied with an abundance of illustration. Perhaps in no department of science is the need of pictorial representation so great as in palæontology, owing to the fragmentary or distorted condition of the bulk of the fossil material. The German edition, which comprises 950 pages, is provided with 2500 woodcuts; the translation promises to increase this number to upwards of 3000. Part 1, which forms the immediate subject of this notice, has fifty-five illustrations more than the corresponding portion of the original. Great discretion has been exercised to select typical

forms for representation, and in the case of diagrams or restorations, pains have been taken to emphasize the more salient features. In some cases, hypothetical restorations that have been since proved to be faulty are altogether discarded, or in other cases are replaced by more perfect ones. In fact, the aim has been to make the pictorial or visualized part not less intelligible and truthful than the descriptive.

As to the subject-matter, the arrangement and coördination is on the whole philosophical and well balanced. In a work of this kind, the relative importance to the palæontologist must be the criterion which governs the amount of space devoted to each group. Hence certain groups which to the zoölogist are of but slight interest are necessarily treated in considerable detail in a palæontologist's manual, and on the other hand numerous subdivisions are passed over unnoticed in the latter, which occupy an important place in zoölogical text-books. In the original, the allotment of space was determined for each class by the author, but in the translation the same ratio has not been preserved, owing to variations in the amount of additional matter contributed by the different collaborations. The result is that some sections have been treated with greater thoroughness than others, but the fault, if it be one, is rather to be commended than condemned. That is, it is better that certain groups receive the painstaking revision of an acknowledged expert, as in the case of the Echinoderms, Bryozoans, or Brachiopods, than that the character of the work as a whole be elevated only a little above the high standard laid down in the original.

This brings us to speak more particularly of the nature of the revision which the English translation has undergone, and also of the classification employed. It was originally intended to bring out a strictly literal translation of von Zittel's *Grundzüge der Paläontologie*, which should follow closely the new German edition. But palæontology is not a fixed science, and fresh discoveries are constantly causing changes and improvements in every system. Hence, to be abreast of the times, a text-book must include the results of the latest authenticated observations, and this can only be done nowadays by enlisting the aid of a body of investigators scattered over the entire field of science. It is to the lasting credit of Professor von Zittel, be it said, that he consented to an arrangement whereby portions of his newly completed treatise were parceled out to a dozen or more specialists for detailed revision and enlargement; and it also speaks

well for the energy of Dr. Eastman in enlisting the sympathy and assistance of the men best fitted for the undertaking. It certainly must require unbounded magnanimity for an acknowledged master of the science to see a work of his, scarcely dry from the press, passing into the hands of different men for the sole purpose of picking it to pieces and building it up again; to see the introduction of a different terminology, or worse still, a classification different from his own; and finally to see the names of other authors appearing at the close of the several chapters, each being awarded a portion of the credit for the excellence of the work. Doubtless all this was not accomplished without a struggle, for it is hard for any one who has long been accustomed to familiar names or systems, to see them encroached upon or entirely replaced by others. It may be questioned whether Continental workers are entirely in sympathy with the younger American school of palæontologists; yet it is clear that so great an author as Karl von Zittel has confidence in their methods, or he would hardly have permitted such changes to be made in his book. His attitude toward this school may also be gathered from a remarkable address before the International Congress of Geologists, reprinted in a late number of the *American Geologist*. We must certainly regard him not only as one of the ablest but as one of the most progressive of modern palæontologists.

To comment briefly upon the various chapters we note first that the Introduction is condensed into sixteen pages, in which the main principles of the science are expounded. The next twenty-five pages are devoted to the Protozoa, Brady's system having been followed in the main for the Foraminifera and Haeckel's for the Radiolaria. The treatment of the sponges, which also occupies twenty-five pages, betrays a master hand. The classification put forward by the author in the *Handbuch*, remains today, with a few unimportant modifications, the best that has been devised. The chief criticism that may be urged against this section is the adoption of too many needless terms proposed by Rauff; the figures and descriptions, however, are of their usual excellence, and the same is true of the corals. The author has been very conservative in his handling of both the Anthozoa and Hydrozoa. It would have been well had a greater notice been taken of American forms, and a more natural classification adopted. It is evident that pages 103–5 are to be considered as replaced by the more extended treatment of the same forms under the Bryozoa, and their double insertion may be overlooked in consequence. It is to be

regretted also that the graptolites were not more extensively described, although abundant references to the literature are supplied at the end of the chapter.

Coming to the Echinoderms, which occupy 125 pages, we note the first great innovation, as nearly the whole section has been fundamentally revised and enlarged. The late eminent crinologist, Mr. Charles Wachsmuth, is mainly responsible for the condition of the Crinoids and Blastoids, valuable notes, however, having also been supplied by Mr. F. A. Bather and Dr. Otto Jaekel. The Ophiuroids and Asteroids were put in their present excellent condition by Mr. Percy Sladen, vice president of the Linnean Society, and to the same high authority credit is due for having revised the entire Echinoid chapter in accordance with the latest approved classification. Some notes on the Worms were contributed by Dr. G. J. Hinde, but this section is not appreciably extended.

The subkingdom Molluscoidea is the next to claim our attention. The chapter on Bryozoans has been entirely rewritten and greatly extended by Mr. E. O. Ulrich. Such a detailed treatment as this part presents would have been more appropriate for a handbook of palæontology than for an elementary treatise, but the unusually large amount of space devoted to the group is excusable perhaps on account of the absence of a correspondingly larger work to which students may refer. Nevertheless we are fortunate in having an extended account of this difficult group made so accessible.

The chapter on the Brachiopods may be regarded as the latest and highest authority for our knowledge on the subject. It has been very skillfully drawn up by Mr. Charles Schuchert, of the U. S. National Museum, and has received some additional illustrations from the writings of Professor C. E. Beecher. The classification adopted is that employed by Mr. Schuchert in his excellent "Synopsis of American Fossil Brachiopoda," and represents an extension of the system originated by Professor Beecher. Every known genus of Brachiopods, fossil and recent, finds notice here, and the condensation is marvelous. The work could have been amplified to almost any desired extent, but it could hardly have been more complete, concise, and clear. It goes without saying that the synonymy indicated is approved by the leading authorities on this group. Considering the scope and nature of the text-book it is difficult to see how this chapter could have been very materially improved.

Only the introduction to the Pelecypods is contained in Part 1, but its improvement over the original is manifest, and we are able to form some idea of what may be expected from Dr. Dall, on this group and the Gastropods. The appearance of the concluding part of the first volume will be awaited with great interest, since without doubt the contributions of Messrs. Hyatt, Beecher, Clarke, Scudder, and others who are understood to be engaged on its revision will so elevate the character of the work as to render it the standard authority on the subject for years to come.

Palæontological science is certainly beholden to Wachsmuth, Sladen, Ulrich, Schuchert, Dall, and the others for their labors of love in trying to make this an authoritative and trustworthy text-book. How well they have succeeded remains to be determined after the book has been used in the laboratory, and it is certainly to have a wide use here. The improvement is so marked over the German edition, the "translation" contains so little from the original, and the "revision" is so complete that the question naturally arises whether Dr. Eastman could not just as well have gone a little farther in his work and made it a text-book by American authors which would have held the same place among English-speaking people as the original *Handbuch* does among the Europeans.

CHARLES R. KEYES.

Die Eruptivgesteine des Kristianiagebietes. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol. By PROFESSOR W. C. BRÖGGER. Pp. 1–183, with 19 figures in the text. Kristiania, 1895.

For the purpose of gaining more light upon certain eruptive relationships of the rocks of the Christiania region, Professor Brögger and his friend Professor Ussing spent eight days in studying this classic locality of the south Tyrol. In a delightful introduction some idea is given of the perennial interest of the region to geologists by reference to the long roll of the most famous workers in geology preserved in the old guest-book of the "Golden Ship" at Predazzo.

The name *monzonite* (from the village of Monzoni) was first applied to the eruptive rocks of this region by Lapparent in 1864, but since his time different authors have used it in various senses. The earlier writers usually referred to these rocks as syenites. Tschermak in 1869

defined monzonite as a peculiar rock varying between syenite and diorite as extremes. His name was for a *geological* unit, however, and was not a petrographic definition. Dölter in 1875 adopted a similar usage; hand specimens of monzonite were syenite, diorite, gabbro, augitfels, or diabase. Rosenbusch, Teall, and Zirkel refer to monzonite as augite syenite. Nearly all writers have agreed in regarding the rocks of this locality as a series of intimately related members, ranging from acid to basic chemical composition, but have differed as to which is the main type.

In the laboratory the author's collection of specimens was found to fall into two groups — an acid group with 50–60 per cent. of silica, and a basic group with less than 50 per cent. of silica. The former group is the main one and embraces the monzonites proper, which are orthoclase-plagioclase rocks; while the latter are pyroxenites, and are merely peripheral facies of the monzonite, into which they grade. The term ***monzonite*** is thus given definite petrographic significance as the name of a transition or intermediate group of rocks between the orthoclase rocks (syenites) on the one hand, and the plagioclase rocks (diorites) on the other. The former method of uniting such a transition group with one or other of the limiting members of the series would, in this case, fail to express the most characteristic thing about these rocks, viz., that they contain plagioclase and orthoclase in about equal proportions.

Chemical investigation still further shows the need for a special name for the group. The probable range in silica percentage in all the monzonites is from 62–60 per cent. down to 50–48 per cent. This excludes all granites, quartz diorites, and quartz syenites from the comparison. The gabbros, too, are mostly more basic, have lower alkali contents, higher lime, and generally higher magnesia and iron oxides. A direct comparison, then, is necessary only with the syenites and diorites. The nepheline syenites have about the same silica contents as the monzonites, but are otherwise very different, as is shown by the following ratios deduced from thirteen analyses of nepheline syenites, and five of monzonites:

Nepheline syenite - -	$Ca : Na_2O : K_2O :: 1 : 4 : 2$
Monzonite - - -	$CaO : Na_2O : K_2O :: 10 : 4 : 3$

The chemical affinities of monzonite with the syenites and diorites are shown in the following table. All the analyses used for compari-

son were carefully chosen so as to secure typical and unaltered plutonic rocks.

	Potash Syenite	Soda Syenite	Monzonite	Diorite
SiO_2	60.57	58.32	55.88	56.52
TiO_2	.53	.54	not det.	.25
Al_2O_3	15.85	18.23	18.77	16.31
Fe_2O_3 (FeO, MnO)	8.23	7.16	8.20	11.09
MgO	2.59	1.31	2.01	4.32
CaO	4.44	4.12	7.00	6.94
Na_2O	2.13	5.70	3.17	3.43
K_2O	6.02	3.84	3.67	1.44
H_2O	1.06	1.02	1.25	1.03
P_2O_5	.58	.54	not det.	.40
	Mean of 3 Analyses	Mean of 10 Analyses	Mean of 5 Analyses	Mean of 16 Analyses

In the syenites the lime is low and the alkalies high; in the diorites the lime is high and the alkalies low; in monzonite they are about equal. Study of the analyses shows that the monzonites form a chemically well-characterized "*Zwischengruppe*" between the syenites and diorites. They are true plutonic rocks of intermediate composition, with a medium lime percentage (6–7 per cent.), about the same amount of total alkalies, equally divided between potash and soda, high alumina (about 17–18 per cent.), and relatively low magnesia contents.

The structure of monzonite is that of a plutonic rock and is characterized by the fact that the orthoclase crystallized last in large allotriomorphic plates (*mesostasis*), partially enclosing the other minerals. The latter are plagioclase (usually labradorite or andesite) and augite. Olivine is abundantly present in certain basic members, but lacking in the more acid ones. Biotite, hypersthene, and hornblende occur sparingly. The accessory minerals are titanite, zircon, apatite, and iron ores.

Outside of the south Tyrol, rocks corresponding to monzonite have been described from Norway, Saxony, Schemnitz, Minnesota, and other parts of the world. An olivine monzonite occurs at Smälingen, while a rock from Rougstock, in the Bohemian Mittelgebirge, is a nepheline-bearing monzonite, and occupies a place between monzonite or augite diorite and theralite. The relations of monzonite to the syenites and diorites are graphically shown by a diagram. Monzonite occupies

the center of a triangle and by increase in soda passes through akerite and lavurikite to nepheline syenite; by increase of potash through plauenite and potash-feldspar-syenite to a hypothetical leucite syenite; and finally, by increase in lime, through alkali-rich diorite and alkali-poor diorite into an acid lime-rich norite, etc.

The pyroxenites of the region are basic peripheral facies of the normal monzonite. They were the first to solidify, as detached masses of pyroxenite are frequently included in the monzonite. The latter rock frequently shows porphyritic facies on its periphery, as is common in the Christiania region.

The monzonites and their peripheral facies are not the only eruptive rocks of Triassic age in this region. The complete series, and the sequence of eruption, is summed up by Brögger as follows:

(1) The oldest eruptions of Triassic time are represented by basic dikes and effusive rocks; melaphyre, augite-porphyrite, amygdaloids, tuffs, etc.

(2) Corresponding to the later eruptions of these basic dikes and effusive rocks, are also basic plutonic rocks (essentially pyroxenite, passing into gabbro-diabase, monzonite, etc.) of which relatively only insignificant masses are preserved as peripheral facies of more acid rocks.

(3) These more acid rocks, essentially monzonite, are of intermediate composition and belong to an independent rock-group within the series of the orthoclase-plagioclase rocks.

(4) Younger than the monzonites and the corresponding effusive rocks, are the red granites of Predazzo; also, probably, small veins of aplite and dikes of quartz porphyry.

(5) The youngest eruptions of the whole eruptive epoch are represented by an association of dikes; these are partly of ultra-basic composition, essentially camptonites, and partly of intermediate composition, commonly "liebeneritporphyre," or nepheline-bostonite. These two groups are related as complementary dikes. The bostonites appear generally to represent the youngest eruptions of the whole epoch.

Before applying the facts gained in the Tyrol to the study of the Christiania region, the author discusses the general laws governing the mechanism of eruption of plutonic rocks, and especially the hypothesis due to Kjerulf, Michel-Levy, and Suess, that the granites are batholithic, not laccolithic, and have displaced the invaded rocks by fusing and

assimilating them. He cites cases from the Christiania region where the granite has intruded the sedimentary beds in such a way that a portion of the latter has disappeared. The invading rock has metamorphosed the sediments, but the contact is sharp, and the granitite, which is normally very poor in lime, shows no chemical enrichment through "assimilation" of the calcareous beds with which it is in contact. During years of study, over magnificent exposures, in the Christiania region, Brögger has found no evidence in favor of any assimilation of the invaded sediments, nor for their "feldspathization" by the intruding magma. If the granite, then, has not absorbed the missing beds, where have they gone? They must, he says, be *underneath* the plutonic mass. "The plutonic rocks of the Christiania region have been brought into their present position by purely mechanical processes—by a squeezing up, and subsequent lateral intrusion, as a consequence of great subsidences of neighboring portions of the earth's crust. Their composition is not essentially influenced through assimilation of salbands, or through fusion of the overlying strata, but is the final result of differentiation processes of the original magma of the common magma-basin from which they all come. Their typical form is the '*Kuchenform*' of the laccolith." It is possible, however, that the Michel-Levy assimilation hypothesis and the Suess batholith hypothesis may apply to the great granite regions of the older "*Grundgebirge*" or to districts of folded, regionally metamorphosed rocks, but Brögger evidently considers it improbable.

The eruptive sequence of the Tyrolean region is compared with that of the Christiania region, and the facts are considered to support the view previously advanced by Brögger, that the differentiation sequence and the eruptive sequence are dependent upon the sequence of crystallization. The chemical composition of the hypothetical primary magma of the Austrian region is calculated by the method employed for the Christiania region in the preceding paper on the Grorudite-Tinguaite Series, and is found to have about the same silica percentage (65.2, as compared with 64.2 for the Christiania magma) but is rich in lime and poor in alkalies, while the Norwegian magma is poor in lime and rich in alkalies.

The paper concludes with some general considerations on the eruptive sequence of plutonic rocks. Such sequences are very difficult to work out in the field, and to be of service in determining the laws in accordance with which the differentiation processes have taken place

in a magma-basin, it is necessary to employ observations upon series of genetically connected eruptions, of a definitely bounded region, and belonging to a single eruptive period. The work of Iddings, Teall, Dakyns, and Wadsworth has shown that the *normal* series is basic—less basic—acid. This agrees with the explanation of differentiation through a diffusion toward the cooling surface of a magma-basin, which is regulated by the ordinary sequence of crystallization. According to Brögger the effusive rocks are in great part the products of a *secondary* differentiation from plutonic magmas; and, in general, the further away the magma-masses are from the original mother-magma, the more they have been subjected to secondary differentiation and the less regularity is observable in their eruptive sequence.

F. L. RANSOME.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.[1]

Gibson[2] gives a summary, from the reports of the Canadian Geological Survey, of the pre-Cambrian geology of the Hinterland of Ontario.

Coleman[3] gives a summary of the geology of the Rainy Lake region. Following Lawson, the rocks are classified as follows:

Archean	Upper division.	*a.*	Keewatin. (Huronian ?)
		b.	Coutchiching.
	Lower division.		Laurentian.

The Laurentian rocks consist chiefly of granite-gneisses, with subordinate quantities of granite and syenite. The Coutchiching consists of fine-grained mica-schists and mica-gneisses which show rapid changes in composition in passing from one layer to another, thus suggesting sedimentation. These rocks are usually sharply separated from the Laurentian, but at Rice Bay the writer found himself in doubt as to the classification. The Coutchiching series is regarded as a metamorphosed sedimentary one. As to the source of the material there is no very definite information, unless certain gneisses in Sand Island river having layers differing sharply in composition be looked upon as remnants of an original Laurentian floor. The Keewatin is a series of eruptive and fragmental rocks of great thickness and variety, consisting broadly of a lower division of basic eruptives and volcanic ashes, and an upper acid division. The bulk of the lower basic portion consists of diabases, with some gabbros and anorthosites, and apparently some diorites. Porphyroids are also present. The schistose members, often interbedded with the massive altered eruptives, near the contact with the

[1] Continued from p. 372, Vol. IV., JOURNAL OF GEOLOGY.

[2] The Hinterland of Ontario, by T. W. GIBSON. Fourth Rept. Ontario Bureau of Mines, 1894, Sec. III, part on pp. 124, 125. Toronto, 1895.

[3] Gold in Ontario: Its Associated Rocks and Minerals, by A. P. COLE. Fourth Rept. Ontario Bureau of Mines, 1894, Sec. II, pp. 35–100. Accompanied by two geological maps of parts of the Rainy River district. Toronto, 1895.

Laurentian are chiefly hornblende-schists, but in other localities are chlorite-schists. Between these two are numerous transitions. Graywackes occur at several localities, and agglomerates and conglomerates are plentiful. The upper acid division includes felsites, sericite-schists, and quartz-porphyries. These are apparently younger than the green schists and massive rocks of the Keewatin, but the two divisions are conformable, as is also the whole of the Keewatin to the Coutchiching. The rocks included in the Laurentian are, for the most part at least, intrusive in the Coutchiching and Keewatin. In the Keewatin are various intrusive granite areas. Cutting all of the previous series are dike rocks, which may be divided into an acid division, including granite and pegmatite, and a basic division, including diabase and quartz-diabase.

Many details are given as to particular occurrences of the various rock series. The occurrence of gold in Ontario is described, and incidentally the rock succession in the Hastings district is summarized.

Winchell and Grant[1] give a preliminary account of the Rainy Lake gold region. Following Lawson, the rocks there found are separated into four distinct groups. Beginning with the lowest these are: (1) Laurentian, composed of granites and granitoid gneisses and allied rocks; (2) Coutchiching, composed of mica-schists grading into fine-grained gneisses; (3) Keewatin, composed of hornblendic, greenish, and sericitic schists, conglomerates, graywackes, etc.; (4) Diabase dikes, more recent than and cutting all the others. The Coutchiching mica-schists have in many places rapid alternations in bands from an inch to several feet in width of slightly different mineralogical composition, structure, or color. The position of these bands gives the strike and dip of the rock, and when they are lacking the schistose structure is taken as giving the strike and dip, as this seems to be parallel with the banding when the two are seen together. On account of basal conglomerate beds in places in the Keewatin resting on the Coutchiching, while an unconformity between the two is not proven, it seems quite probable.

COMMENTS.

The banding of the Coutchiching mica-schists in many places described by Coleman, Winchell, and Grant is just such as has been

[1] Preliminary Report on the Rainy Lake Gold Region, by H. V. WINCHELL and U. S. GRANT. 23d Ann. Rept. Geol. and Nat. Hist. Sur. of Minn., for 1894, Part II, 1895, pp. 36–105.

ascribed to igneous rocks in other localities, and it yet remains to be proved that the series is sedimentary. Even if sedimentary, no satisfactory evidence is given that either the schistosity or banding corresponds with bedding. Using the classification of the United States Geological Survey, the Keewatin or a part of it would be regarded as Huronian, and the Coutchiching or a part of it would be regarded as Archean. It is rather probable that in the Thunder Bay district of Ontario and in northeastern Minnesota parts of two series have been included under each of these terms.

Smyth and Finlay[1] describe the western part of the Vermilion range. The sedimentary rocks fall into two divisions. The older is a fragmental slate formation, while the younger is an iron-bearing formation lithologically identical with certain phases of the lower iron-bearing formation of the Marquette district. To all appearances it is devoid of clastic material. It is believed, from analogies with other iron-bearing districts of the Lake Superior region, that the jasper of the Vermilion district is derived from a cherty iron carbonate or from a glauconitic greensand, or both. However, as the jasper is a final product of the alterations, it is not possible to show this.

Intrusive igneous rocks are very abundant, cutting or being interleaved with the sedimentary rocks in masses running from the thickness of a knife blade to those 100 feet across. In quantity the igneous rocks exceed, perhaps several times the sedimentary rocks. The oldest igneous rocks are greenstones. These vary from massive to schistose, and into conglomerate-breccias. The acid rocks were intruded later than the basic rocks. They were originally for the most part quartz-porphyries, but these have been extensively changed to sericite-schists and conglomerate-breccias, and to rocks intermediate between these and the original form. Within the larger masses of the igneous rocks, both basic and acid, are frequently included fragments from both the slate and iron formations, from those of small size to masses more than 100 feet long.

The conglomerate-breccias are of dynamic origin. The first step in the development of the breccias was the formation of two intersecting sets of planes of fracture, dividing the originally massive rocks

[1] The Geological Structure of the Western Part of the Vermilion Range, Minn., by H. L. SMYTH and J. RALPH FINLAY. Trans. Am. Inst. of Min. Engineers, Vol. XXV, 1895, pp. 595–645.

into roughly rhomboidal blocks. Their further development depended on continued movement between these blocks under pressure, which resulted in enlarging the shearing zones at the surfaces of contact, and rounding the angles. The slate and jasper inclusions originally plucked off from the rocks which the porphyries and greenstones invaded, shared, of course, the subsequent history of their captors. The fact that the jasper inclusions are frequently rounded, while those of slate are not, is explained by the difference in the elasticity of the two rocks. The slate inclusions readily yielded and finally took a permanent set under the deforming forces, while the harder and more rigid jasper, in fragments of limited size and diverse orientation, behaved like the enclosing porphyry. The boundaries of the inclusions were generally the surfaces along which rupture took place, although, as has already been said, jasper in a few instances is found partly held in porphyry inclusions.

As to structure, the main slate area is anticlinal; both north and south of this area the jasper succeeds the slates. The southern jasper continues in a complex syncline, and south of this is found the northern limb of another anticline of slates, the southern limb not being exposed. Still farther south is the jasper of Lee and Tower Hills, which appears to form the southern and western edges of a complex syncline. All of these folds pitch toward the east.

The ore deposits are found to conform in occurrence to the laws worked out by Van Hise in reference to other districts of the Lake Superior region; that is, (1) they occur for the most part in pitching troughs with impervious basements. Usually this impervious basement is one or more of the different varieties of the eruptive rocks. (2) They are secondary concentrations produced by downward percolating waters, the silica being leached out and the iron ore deposited.

Smyth, (H. L.),[1] describes a quartzite tongue in the jasper at Republic. This tongue branches from the main mass of quartzite, and after continuing nearly parallel with it for a long distance, tapers to a point toward the north in a mass of specular jasper. The quartzite tongue includes between itself and the main quartzite a similar jasper tongue, which starts in the north from the jasper, and tapers to a point toward the south in the quartzite, the two tongues interlocking. These

[1] The Quartzite Tongue at Republic, Michigan, by H. L. SMYTH. JOURNAL OF GEOLOGY, Vol. II, 1894, pp. 680–691.

unusual relations are explained as due to faulting approximately parallel to the fold which occurred during the folding of the series.

Van Hise[1] describes the rocks of the Marquette district as constituting a great synclinorium. The axial planes of the minor folds on the sides dip toward the center of the synclinorium, thus resembling the fan structure of the Alps; but there is the great difference that the major fold is a synclinorium rather than an anticlinorium. This kind of fold may be called the Marquette type.

Clements[2] describes the volcanic rocks of the Michigamme district of Michigan. The succession in the district from the base up is (1) granite and gneiss, cut by basic dikes; (2) quartzose limestone formation, with an estimated thickness of 1500 to 2000 feet; (3) a great series of volcanics, with an average thickness of about 3000 feet; (4) a set of sedimentaries consisting of quartzites, slates, and iron formation material. The volcanics include apobasalts, apo-andesites, and aporhyolites, each occurring both as lavas and as tuffs. The lavas are frequently amygdaloidial.

Smyth (H. L.),[3] compares the Lower Menominee and Lower Marquette series in Michigan. The Lower Menominee series consists in ascending order of

1. A basal quartzite, rarely conglomeratic, having a thickness of 700 to 1000 feet.

2. A crystalline limestone, averaging 700 to 1000 feet in thickness.

3. Red, black, and green slates, not known to exceed 200 or 300 feet in thickness, and containing the iron formation that gives the rich ores of Iron Mountain and Norway. Toward the north the horizon of the slates is in part occupied by later eruptives, that rapidly increase in thickness and attain a maximum of nearly 2000 feet.

4. The Michigamme Mountain jasper. The least modified phase seems to be in part at least a sediment. The most highly altered kind is like the banded, specular jasper of Republic.

[1] Character of Folds in the Marquette Iron District, by C. H. VAN HISE. Proc. Am. Assoc. for Adv. of Sci., for 42d Meeting, 1894, pp. 171. (Abstract.)

[2] The Volcanics of the Michigamme District of Michigan (preliminary), by J. MORGAN CLEMENTS. JOURNAL OF GEOLOGY, Vol. III, 1895, pp. 802–822.

[3] Relations of the Lower Menominee and Lower Marquette Series of Michigan (preliminary), by H. L. SMYTH. Am. Jour. Sci. (III), Vol. XLVII, 1894, pp. 216–223.

The Lower Marquette series in the western part of the Marquette area consists in ascending order of

1. A basal conglomerate, quartzite, quartz-schist — probably less than 100 feet.

2. An iron-bearing formation which may be divided into a lower actinolitic schist and an upper banded red jasper and specular hematite. The iron-bearing member has a maximum thickness of more than 1000 feet.

The magnetic jasper of Michigamme mountain by means of outcrops and magnetic work, has been traced within one and one-half to two miles of the iron-bearing formation of the Marquette series, and the two are regarded as equivalent. If this be true, the Lower Marquette quartzite may represent the lower quartzitic portion of the Michigamme jasper formation, in which case the whole of the Lower Marquette series would be represented by the highest member of the Lower Menominee.

The absence in the Marquette district of the equivalent of the great thickness of limestone, quartzite, and eruptives below the Michigamme jasper in the Menominee district is accounted for by supposing that the Marquette area was more elevated, and that the transgression of the ocean from the south reached the Marquette district when the lower portion of the Michigamme jasper was being deposited. If the above correlation be correct it further follows that the principal ore formation of the Menominee has no equivalent in the Marquette district.

The Mount Mesnard series of quartzite, limestone, and slates, as described by Wadsworth, in the eastern part of the Marquette area, between the Cascade range and Lake Superior, has many points of resemblance to that part of the Lower Menominee series below the Michigamme jasper. The age of the Mount Mesnard series is still in doubt, but if it should prove to underlie the Lower Marquette (Wadsworth's Republic formation), its position would probably indicate the limit of the old Marquette highland on the eastern side.

COMMENTS.

One point upon which additional evidence seems to be necessary is that the slates bearing iron ores in the Menominee district proper are really equivalent to the slates associated with eruptives farther north. If these are not equivalent, it is possible that the Michigamme

jasper and these iron-bearing slates are the equivalents of the iron-bearing formation and the quartzite below in the Marquette district. If the latter proves true the principal ore horizon of the Menominee may have an equivalent in the Marquette district.

Weidman[1] describes the igneous rocks of the Lower Narrows of the Baraboo River. These are in a belt from one-eighth to one-half mile wide, running for four miles in a direction east and west. Chemical and microscopical study shows this rock to be a quartz-keratophyre. It is shown to be a volcanic rock by its flowage structure, broken crystals, and by volcanic breccias. The rock has a schistosity parallel to the bedding of the quartzite. The quartz-keratophyre rests upon the topmost layer of quartzite, with a possible erosion interval. It has been folded with the quartzite, and like that rock rests unconformably below the undisturbed Cambrian.

Beyer[2] describes spotted slates associated with the Sioux quartzite series in the northeast corner of Minnehaha county, South Dakota. The quartzite here grades up into reddish slate, which in lithological character corresponds to the quartz-slate described by Irving and Van Hise in the Penokee series of Michigan and Wisconsin.

Bayley[3] gives fully the field occurrences, relations, and petrography of the eruptive and sedimentary rocks of Pigeon Point. The oldest rocks are interbedded Animikie slates and quartzites. Cutting the Animikie rocks is an olivine-gabbro, which occupies all the higher portions of the point. It is in all probability the lower portion of a large dike, whose upper part has been removed by denudation. Between the gabbro and the bedded rocks in many places are successively a coarse-grained red rock, a fine-grained red rock (quartz-keratophyre) and a series of contact rocks. The main masses of the keratophyre occupy a position between the Animikie sedimentaries

[1] On the Quartz Keratophyre and Associated Rocks of the North Range of the Baraboo Bluffs, by SAMUEL WEIDMAN. Bull. Univ. of Wis., Sci. Ser., Vol. I, 1895, pp. 35–56, pls. 1–3.

[2] The Spotted Slates Associated with the Sioux Quartzite. by S. W. BEYER Johns Hopkins Univ. Circulars, No. 121, 1895, p. 10.

[3] The Eruptive and Sedimentary Rocks on Pigeon Point, Minn., and their contact phenomena, by W. S. BAYLEY. Bull. 109, U. S. G. S., with maps and plates. Washington, 1893.

and the gabbro. This rock has all the characteristics of an eruptive younger than the gabbro. The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between the two, and grade into them. They are therefore regarded as a contact product formed by the intermingling of the gabbro and keratophyre magmas. The keratophyre also apparently grades into the Animikie slates and quartzites, there being three zones showing different grades of alteration of the sedimentary rocks, due to the contact with the igneous rock.

From the peculiar relations it is regarded as probable that the keratophyre is of contact origin; that is, it was produced by the fusion of the slates and quartzites of the Animikie through the action upon them of the gabbro. The magma thus formed then acted in all respects like any intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda-granite under certain circumstances, and under others as a quartz keratophyre. Cutting all of the previously mentioned rocks are diabase dikes.

Bayley[1] gives a detailed petrographical study of the basic, massive rocks of the Lake Superior region and especially of the great gabbro of northeastern Minnesota. The normal phase of the gabbro is found to have a typical granitic structure and to differ essentially from all of the basic intrusive rocks of the Animikie series and from all other Keweenawan basic rocks, none of which have a distinctly granitic structure. Upon the border of the main mass of gabbro are peculiar rocks which are interlaminated with quartzose bands. These are shown to be but peripheral phases of the gabbro. It is concluded that further field work will probably show that the gabbro is either a batholite, well toward the base of the Keweenawan series, or that it is a eroded mass upon top of which the later Keweenawan beds have been deposited.

Elftman[2] finds that the great gabbro of northeastern Minnesota has a rude arrangement of the rock in parallel layers similar to the

[1] The Basic Massive Rocks of the Lake Superior Region, by W. S. BAYLEY. JOURN. OF GEOL., Vol. I, 1893, pp. 433–456, 587–596, 688–716; Vol. II, 1894, pp. 814–825; Vol. III, 1895, pp. 1–20.

[2] Notes upon the Bedded and Banded Structures of the Gabbro and upon an Area of Troctolyte, by A. H. ELFTMAN, 23d Ann. Rep. Geol. and Nat. Hist. Sur. of Minn. for 1894, part XII, 1895, pp. 224–230.

layers of sedimentary rocks. This structure usually dips to the south. It does not depend upon the differentiation of the mineral components of the rocks, but seemingly is due to secondary causes which acted upon the rock after it had solidified. This sheeted structure is a common phenomenon along the northern limits of the mass. The gabbro has also a banded structure due to the parallel arrangement of the mineral constituents. The bands are not regularly arranged, appearing and disappearing in a manner which shows them to be not independent of the secondary causes. This structure is present to a marked degree in the central portion of the gabbro.

Large feldspar masses occur in the gabbro in the southeastern parts of T. 61 N., Rs. 10 W. and 11 W. The mass in the latter township has a marked banding. The line of division between the feldspar masses and the normal rock is sharp in the field and in the hand specimen. Both are, however, regarded as differentiations from the same magma.

In the southern part of T. 62 N., R. 10 W., the eastern part of T. 61 N., R. 11 W., the greater part of T. 61 N., R. 10 W., and in adjacent townships is a considerable area of dark, reddish-colored olivine-gabbro or troctolyte, which has both a sheeted and banded appearance. This rock and the normal gabbro have not been seen in contact, but wherever they closely approach each other, often within a few feet, both preserve their characteristic structure, and there is no sign of the transition of the one into the other. The olivine rock appears to be above the ordinary gabbro.

Hubbard[1] gives two geological cross-sections of the Keweenawan series in the vicinity of the Calumet and Hecla and the Tamarack mines. The strata here consist of interstratified traps, amygdaloids, sandstones, and conglomerates. Deep in the series there is less amygdaloid, and it is suggested that the amygdaloids are largely pseudo-amygdaloidal, their development being dependent upon sub-surface weathering. It is found that the conglomerates approach each other in passing from the north toward the south, due to the thinning of the igneous beds. The Eastern sandstone, somewhat remote from the line of junction with the Keweenawan series, has at places a dip toward the traps as high as 10° or 12°. At Lake Linden this formation is

[1] Two New Geological Cross-sections of Keweenaw Point, by L. L. HUBBARD. Proceedings of the L. S. Mining Inst., Vol. II, 1894, pp. 79–96.

shown by boring to be at least 1500 feet thick, and to consist of red sandstone with several streaks of marl. The likeness of this sandstone to the upper Keweenawan sandstone, the faulting along or near the contact line of the two formations, and the thinning of the traps and amygdaloids in passing toward the Eastern sandstone, seem to strongly favor the theory that the two formations are of the same age.

COMMENTS.

The question of the relations of the Eastern sandstone to the Keweenawan is too difficult a one to discuss here, but it may be said that it is the reviewer's opinion that the evidence presented is far too slight for so important a conclusion. For a comprehensive discussion of the question the reader is referred to Bulletin 23 of the United States Geological Survey.

Winchell,[1] discusses the origin of the Archean greenstones. The great bulk of them are pyroclastic. They were distributed and somewhat stratified by the waters of the ocean into which the material fell. As evidence of their arrangement by water is their very general stratiform structure, which can only be explained by the action of water. This structure stands vertical or nearly so. These greenstones constitute a distinct terrane, forming the latest portion of the Keewatin, at the top of the Fundamental Complex of the Lake Superior region. Below the greenstones are found chloritic slates and schists, chloritic schists, clay-slates, graywackes, conglomerates, quartzites, novaculites, and jaspilites. The thickness of the greenstones in Minnesota exceeds that of any other Archean terrane. The Keewatin passes gradually down into crystalline mica-schists or hornblende-schists, and finally into acid gneiss.

COMMENTS.

In certain parts of the Lake Superior region the greenstones are predominantly pyroclastic, and in other parts are predominately intrusive or extrusive lavas. Not only is this so, but within the same series in the same district the basic igneous rocks in one part are mainly tuffs, and in other parts are almost wholly massive.

I would altogether dissent from the conclusion that the banding of the igneous rocks alone is evidence of their arrangement by water. In

[1] The Origin of the Archean Greenstones, by N. H. WINCHELL. 23d Ann. Rep. Geol. & Nat. Hist. Sur. of Minn., for 1894, Part II, 1895, pp. 4–35.

certain areas and series the banded pyroclastics have been largely deposited in water; in other areas and series there is no evidence whatever of such deposition.

The pyroclastics south of Lake Superior, instead of belonging to a single terrane, belong to at least three, distinct, unconformable series. From the base up these are the Archean or Fundamental Complex, the Lower Huronian, and the Upper Huronian. Furthermore, while year after year evidence has been sought upon this point, we have been wholly unable to show that any of the Archean tuffs of the south shore were deposited in water. However, the tuffs of the Lower Huronian and the Upper Huronian have been largely deposited in water, and between ordinary sedimentary rocks showing little or no tufaceous material and ordinary tuffs which give no evidence of water arrangement, there are all gradations.

Winchell[1] reviews the stratigraphy of the Lake Superior region. In reference to the Keweenawan series he reaches the following conclusions: (1) The eruptive rocks which in Michigan, Wisconsin, and Minnesota have been included in the Keweenawan, consists of two widely differing series of widely separated ages. Included in these pre-Keweenawan eruptives are the great gabbro of Minnesota and the red rocks such as those at the Palisades and at Pigeon Point. This eruptive period is called the Animikie revolution. (2) This period was followed by a long erosion interval, during which were deposited the Sioux quartzites of Dakota, the New Ulm quartzites of Minnesota, the Baraboo and Barron quartzites of Wisconsin, and the quartzites and conglomerates below the Keweenawan diabases in the Penokee district. In the New Ulm quartzites are found "taconite" jasper pebbles, and these are taken as evidence that this material was derived from the Animikie. (3) Following this conglomerate and quartzite is the Keweenawan eruptive age, which separates the Paradoxides horizon from the Dicellocephalus horizon. (4) The Olenellus horizon is separated from the Paradoxides horizon by the disturbance that closed the Animikie.

The general succession for the Lake Superior region is given as follows:

[1] Crucial Points in the Geology of the Lake Superior Region by N. H. WINCHELL, Am. Geol., Vol. XV, 1895, pp. 153–162, 229–234, 295–304, 356–363, and Vol. XVI, 1895, pp. 12–20, 75–86, 150–162, 269–274, 331–337.

Upper Cambrian. *Olenus zone.*		St. Croix. Eastern sandstone. Lake Superior sandstone. Nipigon formation. (The Dicellocephalus — "Potsdam" of New York).	Progressive subsidence.
Taconic (or Middle and Lower Cambrian).	Keweenawan. *Paradoxides zone.*	Keweenawan. Traps and underlying Quartzite and Conglomerate. Potsdam at Potsdam, N. Y., and eastward to the Au Sable River.	
		Non-conformity.	
	Animikie. *Olenellus zone; Foraminifera.*	Animikie slates. Pewabic and Wauswaugoning quartzites. Penokee series. Mesabi iron range. Misquah hills. Gabbro and Anorthosite range. Norian. Upper Laurentian. Bohemian range and South Copper range in Michigan. Minong range, Isle Royal.	
The Great Non-Conformity.			
Archean.	Ontarian.	Keewatin.	
		Coutchiching.	
	Laurentian.		

The following general conclusions are reached as to the Lake Superior region and other parts of the United States:

The rocks of the Cortland series (the clastics), of the original Taconic area, and of the upper series of the Adirondacks are of the same age, *i. e.*, Taconic or Lower Cambrian.

The basic rocks of the Norian or Upper Laurentian system of Canada are of the same age as the gabbros of the Adirondacks.

The Taconic in America embraces all the strata containing any known fossils older than those in the Dicellocephalus or Upper Cambrian. It is separated from the Archean by a profound unconformity.

The Animikie strata in Minnesota and in general the upper iron-

bearing series of the Lake Superior region are of the age of the Taconic.

The Taconic age is represented in the Lake Superior basin, as in New England and Newfoundland, by a great series of quartzites and slates, and a few limestones.

Those rocks which have been described and mapped as Keweenawan embrace three eruptive systems, separable by two erosion intervals marked by basal conglomerates and by faunal differences, viz., the eruptives of the Animikie revolution, those of the Keweenawan proper, and the eruptives of the regions of Thunder Bay and Black Bay.

It is added as a corollary to the foregoing that the ocean which covered the spot where North America was to exist was subject to forces which acted simultaneously over a very wide area, producing oceanic deposits of like nature and of like succession in widely separated regions; and, again, that some other widely operating forces caused the simultaneous elevation, depression, and finally the breaking of the earth's crust and the escape of vast quantities of basic rock at various points far distant from one another.

COMMENTS.

Professor Irving[1] was perfectly well aware that under the term Keweenawan, as used by him, there are included two great divisions of rocks. The coarse gabbros of Wisconsin and Minnesota, cut by red rocks, are so sharply separated from the remainder of the Keweenawan that he was tempted to separate the two and place the former in the Huronian. Between the two he says there is a certain sort of unconformity. His belief in the difference between the two is further emphasized by his map of northeastern Minnesota, on which the two were for the first time given separate colors. The difference, therefore, between Professor Irving[2] and Professor Winchell upon the first conclusion is mainly one of nomenclature.

The reviewer either dissents from each of the remaining conclusions of Professor Winchell, or holds that we have no definite knowledge in reference to them.

C. R. VAN HISE.

[1] The Copper-bearing Rocks of Lake Superior, by R. D. IRVING, Mon. V. U. S. G. S., pp. 144–145, 155–156. 1883.

[2] Classification of Early Cambrian and pre-Cambrian Formations, by R. D. IRVING. 7th Ann. Rep., U. S. G. S., Pl. XLI. 1885–6.

ABSTRACTS.

The Relation between Ice-Lobes South from the Wisconsin Driftless Area. By FRANK LEVERETT, Denmark, Iowa.

Instead of a coalescence of ice-lobes from the east and west sides of the driftless area in the drift-covered district to the south there was an invasion and withdrawal of one lobe (the western) before the other reached its culmination. The eastern lobe encroached upon territory previously glaciated by the western, depositing a distinct sheet of drift and forming at its western limits a well-defined morainic ridge. There appears to have been a period of considerable length between the withdrawal of the western lobe and the culmination of the eastern.

Subsequently, however, there was a readvance of the lobe on the west into northeastern Iowa, and this readvance appears to have been contemporaneous with the nearly complete occupancy of northwestern Illinois by the eastern ice-lobe. It seems not improbable that the ice-lobes were then, for a brief period, coalesced for a short distance about the south border of the driftless area. Evidence of complete coalescence, however, is not decisive so far as yet discovered.

These developments serve to throw light upon the cause for the scarcity of lacustrine deposits in the driftless area. They show that there was at most but a brief period in which the southward drainage of the driftless area was completely obstructed by the ice-sheet.

The Production of Coal in 1894. By EDWARD W. PARKER. *Extract from the 16th Annual Report of the U. S. Geological Survey, Part IV., Mineral Resources of the United States.*

This report, consisting of 224 pages, constitutes the first chapter of Part IV. of the 16th annual report of the Director, the well-known volume of "Mineral Resources" having, by a recent act of Congress, been made a part of the Directors' report. This chapter, with four others, has been published and given to the public in advance of the complete volume. As indicated by the title, the chapter is principally a statistical compilation, giving in great detail the record of coal production

in 1894, with a résumé of the industry in previous years. The tables show the production by fields, such as the Appalachian, the Central, the Western, etc.; by states and by counties in the states. They also show the value of the output, and the number of men employed, and the amount of time taken to win it. The result of the prolonged strike in the bituminous regions is shown in a reduced production in 1894 as compared with 1893 of more than eleven and a half million tons. The loss in labor to the miners and other employés who were thrown out of employment by the strike is shown to have been the equivalent of 5,167,357 men for one day, or of 17,224 men for one year of 300 working days.

The effects of the business depression and general low value for commodities is illustrated in the coal mining industry by a decrease in the value of the product in 1894 of over $22,000,000, more than ten per cent. less than that of 1893, while the amount of the product was only 6 per cent. less than the preceding year.

An interesting feature of Mr. Parker's report is a series of contributions from secretaries of boards of trade, etc., in the larger cities, which furnishes useful information regarding the coal trade of those cities, and the effects of the strike and other influences upon the movement of coal from the producing to the consuming centers.

Merocrinus Salopiæ, n. sp., and another Crinoid, from the Middle Ordovician of West Shropshire. By F. A. BATHER. *Geol. Mag., n. s.*, Vol. III, pp. 71–75, February 1896.

Merocrinus is a genus of dicyclic inadunate crinoids, hitherto recorded only from the Utica shale of Ohio (Ulrich) and the Trenton limestone of New York (Walcott). The discovery of a species in the Middleton group, Meadow Town series of Mincop in Shropshire, England, is therefore of interest to American geologists. It is thus diagnosed: "Radials and Basals, as high as wide. Arms slender, bifurcating at intervals of eight or more ossicles. Brachials wider, or with a slight cornice at their distal margin." The other crinoid described and figured presents peculiar features, especially in the arms, but is too imperfect to be referred to any known genus.

U. S. Geologic Atlas. Folio 10, Harper's Ferry, Virginia; Maryland; West Virginia, 1894.

This folio consists of four pages of descriptive text, signed by

Arthur Keith, geologist; one page of columnar section, a topographic map (scale 1:125000), a sheet showing the areal geology of the district; another showing the economic geology, and a third exhibiting structure sections.

The folio describes that portion of the Appalachian province which is situated between parallels 39° and 39° 30′ and meridians 77° 30, and 78°. The tract contains about 950 square miles, and falls within Washington and Frederick counties, Maryland; Loudoun and Fauquier counties, Virginia; and Jefferson county, West Virginia.

The folio begins with a general description of the province, which shows the relation of the Harper's Ferry tract to the whole. The local features of the drainage by the Potomac and Shenandoah Rivers and their tributaries (Goose, Antietam, and Catoctin Creeks) are treated. The various forms of the surface are pointed out, such as Shenandoah Valley, Blue Ridge, and Catoctin Mountain, and their relations to the underlying rocks are made clear.

Under the heading Stratigraphy the geologic history of the Appalachian province is presented in outline, and the local rock groups are fully described in regard to composition, thickness, location, varieties, and mode of deposition.

The formations range in age from Algonkian to Cretaceous, the greater portion being Algonkian, Cambrian and Silurian. The Silurian rocks appear in Shenandoah Valley, the Cambrian in Catoctin Mountain and Blue Ridge, the Algonkian between these ridges, and the Juratrias east of Catoctin. The Algonkian rocks are chiefly granite and epidotic schist; the Cambrian rocks, sandstones and shales, passing up into limestones; the Silurian rocks, limestones and shales; and the Juratrias rocks, red sandstone and shale and limestone conglomerate. The details of the strata are shown in the columnar section. The manner in which each kind of rock decays is discussed, and how the residual soils and forms of surface depend on the nature of the underlying rock.

In the discussion of Structure, after a general statement of the broader structural features of the province, three methods are shown in which the rocks have been deformed. Of these the extreme Appalachian folding is the chief; next is that developed in the Juratrias rocks; and least in importance are the broad vertical uplifts. Three degrees of extreme deformation appear in the Palæozoic rocks — folding, faulting, and metamorphism — each being best developed in a certain kind

of strata. Between Blue Ridge and Catoctin Mountain the Algonkian or oldest rocks appear on a great anticlinal uplift, with Cambrian rocks on either side. Faults appear chiefly on the west side of this uplift, and metamorphism increases toward its side. In Shenandoah Valley the rocks are folded to an extreme degree, and the strata are frequently horizontal or overturned. The Juratrias rocks always dip toward the west, and are probably repeated by faults different in nature from the Appalachian faults. In the sheet of sections the details of the folds and faults appear.

Economic products of this region comprise copper and iron ore; ornamental stones, such as marble, limestone conglomerate, and amygdaloid; building stones, such as sandstone, limestone, and slate; and other materials like lime, cement, brick-clay, and road materials. The localities of each of these materials are noted and quarries located on the economic sheet, and the character and availability of the deposits are discussed.

Geologic Atlas of the United States. Folio 2, Ringgold, Georgia, Tennessee, 1894.

This folio consists of three pages of text, signed by C. Willard Hayes, geologist; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The district of country covered by this folio lies mainly in Georgia, a narrow strip about a mile in width along its northern border extending into Tennessee. It embraces portions of Dade, Catoosa, Walker, Whitfield, Chattooga, Floyd, and Gordon counties in Georgia, and of Madison, Hamilton, and James counties in Tennessee. The region forms a part of the great Appalachian Valley. Its surface is marked by three distinct types of topography viz.: plateaus, formed by hard rocks whose beds are nearly horizontal; sharp ridges, formed by hard rocks whose beds are steeply inclined; and level or undulating valleys, formed on soft or easily eroded rocks. The plateaus are confined to the western third of the district, and include portions of Lookout and Sand mountains. Their surface is generally level or rolling, with a slight inclination from the edges toward the center, giving the plateaus the form of a shallow trough. They are bounded by steep escarpments rising from 1000 to 1200 feet above the surrounding valleys. The sharp ridges are confined to

the eastern third of the district, while a broad undulating valley occupies its central portion. The latter is drained in part northward by tributaries of the Tennessee and in part southward by streams flowing directly to the Gulf. The divide separating the two drainage systems is broad and low, and there is evidence that the Tennessee River formerly flowed southward across the divide.

Geology—The rocks appearing at the surface within the Ringgold district are entirely of sedimentary origin, and include representatives of all the Palæozoic groups. The oldest rocks exposed are shales, sandstones, and thin-bedded limestones of Lower and Middle Cambrian age. These are called the Apison shale, Rome sandstone, and Conasauga shale. Above these formations is a great thickness of siliceous magnesium limestone, the Knox dolomite, the lower portion probably being Cambrian and the upper portion Silurian. The remaining Silurian formations are the Chickamauga limestone and the Rockwood sandstone. The Devonian is either wholly wanting or is represented by a single thin bed of carbonaceous shale, not over 35 feet in thickness. Above the Chattanooga black shale are the Fort Payne chert, Floyd shale, and Bangor limestone forming the Lower Carboniferous, and the Lookout and Walden sandstones forming the Coal Measures. Most of the formations thicken eastward, and at the same time the proportion of calcareous matter decreases, showing that the land from which the materials composing the rocks were derived lay to the east.

The region has been subjected to compression in a northwest-southeast direction, and the originally horizontal strata would have been thrown into a series of long, narrow folds whose axes extend at right angles to the direction of the compression, or northeast and southwest, The effects of compression were greatest in the eastern portion of the district, where the strata are now all steeply inclined and the basal beds form sharp ridges, while in the western portion considerable areas of strata remain nearly horizontal and form plateaus. Where the folding was greatest there was also much fracturing of the rocks, and the strata on the eastern side of a fracture are in many places thrust upward and across the broken edges of the corresponding strata on the west. Most of the ridges in the district have thrust faults of this character along their eastern basis.

Mineral Resources.—These consist of coal, iron ore, mineral paint, manganese ore, limestone, building stone, and brick and tile clay. The productive coal-bearing formations, the Lookout and Walden

sandstones, occupy the upper portions of Pigeon, Lookout and Sand mountains, having an area in this district of 116 square miles. The Lookout generally contains one, and in some places two or three, workable coal seams, but they are variable in position, extent, and thickness. The Walden sandstone forms a considerable area on Lookout Mountain, and contains at least one valuable seam of coal, which is extensively worked at the Durham mines. Two varieties of iron ore are found in workable quantities. The first is the red fossil or "Clinton" ore, which occurs as a regularly stratified bed in the Rockwood formation, and is worked at various places along the base of Lookout Mountain. The second variety is limonite, which occurs as a pocket deposit at the base of several of the ridges along the eastern border of the district. Associated with the latter, particularly along the faults, are deposits of manganese, generally as nodules scattered through the surface soil.

Geologic Atlas of the United States. Folio 4, Kingston, Tennessee, 1894.

This folio consists of three and one-half pages of text, signed by C. Willard Hayes, geologist; a topographic sheet (scale 1 : 125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° 30′ and 36°, and the meridians 84° 30′ and 85°. The district represented lines wholly within the state of Tennessee, and includes portions of Cumberland, Morgan, Roane, Rhea, Loudon, Meigs, and McMinn counties. Its area is approximately 1000 square miles, and it forms a part of the Appalachian province, being about equally divided between the valley and plateau divisions of the province. The northwestern half of the district is a portion of the Cumberland Plateau. The surface of this half, except in the Crab Orchard Mountains, is comparatively level and has an altitude of between 1800 and 1900 feet. Its streams flow in shallow channels until near the edge of the plateau, when they plunge into rocky gorges which form deep notches in the escarpment. The Crab Orchard Mountains are formed by the uneroded portions of an anticline, the hard bed rising in the form of a low arch. Toward the southwest the hard beds were lifted higher, and have been removed, exposing the easily erodible limestone beneath, and in this the Sequatchie Valley has been excavated. The southeastern half of the district

lies within the great Appalachian Valley, here occupied by the Tennessee River, which flows at an altitude of about 700 feet, and above which rounded hills and ridge rise from 300 to 500 feet higher. The valley ridges have a uniform northeast-southwest trend, parallel with the Cumberland escarpment, their location depending on outcrop of narrow belts of hard rocks.

Geology.—West of the Cumberland escarpment the geologic structure is very simple. The strata remain nearly horizontal, as they were originally deposited, except in the Crab Orchard Mountains, where they bend upward, forming a low arch. East of the escarpment the strata have suffered intense compression, which has forced them into a great number of narrow folds whose axes extend northeast and southwest. The strata dip more steeply on one side of the arch than on the other; and as a further effect of compression, the beds on the steeper (generally the northwestern) side have been fractured and the rocks on one side thrust upward across the broken edges of those on the other. In this manner the folds first formed have in most cases been obliterated, and there remain narrow strips of strata separated by faults, and all dipping to the southeast.

The rocks appearing at the surface are entirely sedimentary—limestones, shales, sandstones, and conglomerates—and include representatives of all the Palæozoic groups. The Cambrian formations consist of the Apison shale, Rome sandstone, and Conasauga shale, a series which is calcareous at top and bottom and siliceous in the middle. The Conasauga passes upward through blue shaly limestone into the Knox dolomite, a formation about 4000 feet in thickness, composed of siliceous or cherty magnesian limestone. Probably the lower portion is of Cambrian age, while the upper is undoubtedly Silurian. Above the dolomite is the Chickamauga limestone, whose upper portion toward the eastern side of the district changes from blue flaggy limestone to calcareous shale, and is called the Athens shale. The next formation is the Rockwood, which also changes toward the east from calcareous shale to hard, brown sandstone. These changes in the character of the rocks indicate that, while they were forming, the land from which their materials were derived lay to the southeast. The Devonian is represented in this region by a single stratum of carbonaceous shale, the Chattanooga black shale, which rests, probably with a slight unconformity, on the Rockwood. Above the Chattanooga are the Fort Payne chert and Bangor limestone of the lower

Carboniferous, and the Lookout and Walden sandstones of the Coal Measures.

Mineral resources.—These consist of coal, iron ore, limestone, building stone, and clay. The coal-bearing formations, the Walden and Lookout, form the surface of the greater part of the district northwest of the Cumberland escarpment, making a probably productive area of 370 square miles. The Lookout always contains one and sometimes as many as four beds, all of which are locally though not generally workable. The upper bed, immediately below the conglomerate, is the most constant. The greater part of the workable coal is contained in the Walden, the lower bed probably corresponding to the Sewanee seam farther west. This occurs in a belt six or eight miles in width along the eastern edge of the plateau. The only iron ore sufficiently abundant to be commercially important is the red fossil ore, which occurs as a regularly stratified bed in the Rockwood formation. The numerous folds east of the escarpment bring the Rockwood to the surface in long, narrow bands, along which the ore has been worked at many points. It varies in thickness from three to seven feet, and although at some places it passes into a sandy shale, it is generally a high grade ore.

Geologic Atlas of the United States. Folio 6, Chattanooga, Tennessee, 1894.

This folio consists of three pages of text, signed by C. Willard Hayes, geologist; a topographical sheet (scale 1 : 125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° and 35° 30′ and the meridians 85° and 85° 30′. The district is wholly within the State of Tennessee, embracing portions of Bledsoe, Rhea, Sequatchie, Marion, Hamilton, and James counties. It lies partly in the great Appalachian Valley and partly in the plateau division of the Appalachian province. Its surface is marked by two distinct types of topography, the plateau and the valley. The former prevails in the western half of the district, which is occupied by portions of the Cumberland Plateau and Walden Ridge, the two plateaus being separated by Sequatchie Valley. The Cumberland Plateau has an altitude of about 2100 feet, with a level or rolling surface. Walden Ridge has an altitude of 2200 feet along its western edge, and slopes gradually eastward down to 1700 feet. Both plateaus are bounded by abrupt escarpments

from 900 to 1400 feet in height, the upper portions being generally formed by a series of cliffs. The two plateaus are separated by Sequatchie Valley, which is about four miles in width. Its western side, the escarpment of Cumberland Plateau, is notched by numerous deep, rocky gorges, cut backward into the plateau by streams flowing from its surface; while the eastern side, the Walden escarpment, forms an unbroken wall. The eastern half of the district is occupied by the Tennessee Valley, the river itself having an altitude of between 600 and 700 feet, while rounded hills and irregular ridges rise several hundred feet higher. Leaving the broad valley, which continues southward into Alabama, the Tennessee River turns abruptly westward at Chattanooga and enters a narrow gorge through Walden Ridge. This part of its channel is very young in comparison with the valley toward the north, and there is evidence that the river has occupied its present course but a short time, having formerly flowed southward directly to the gulf.

Geology.—The rocks appearing at the surface within the limits of the map are entrely of sedimentary origin, and include representatives of all the Palæozoic groups. The Cambrian formations include the Apison shale, Rome sandstone, and Conasauga shale,-a series which is calcareous at top and bottom and siliceous in the middle. The Conasauga passes upward through the blue limestone into the Knox dolomite—a great thickness of siliceous magnesium limestone, the lower portion of which is probably Cambrian. Above the dolomite are Chicamauga limestone and Rockwood shale, the latter becoming brown sandstone in White Ash Mountain. The whole of the deposition which took place in this region during the Devonian is apparently represented by a stratum of shale from ten to twenty-five feet in thickness—the Chattanooga black shale, which probably rests unconformably upon the Rockwood. Above the Chattanooga are the Fort Payne chert and Bangor limestone, forming the lower Carboniferous, and the Lookout and Walden sandstones, forming the Coal Measures. Nearly all the formations exhibit an increase in thickness and in proportion of sand and mud toward the east, showing that the land from which their materials were derived lay to the east and southeast.

The geologic structure is simple in the region occupied by the plateaus, and complicated in the valleys. In the Cumberland Plateau the strata are almost perfectly horizontal, while in Walden Ridge they have a slight dip from the edges toward the center. Sequatchie Valley

is located upon the westernmost of the sharp anticlines which characterize the central division of the Appalachian province. In the eastern part of the district the strata have suffered compression, which has forced the originally horizontal strata into a series of long, narrow folds whose axes extend in a northeast-southwest direction. In addition to the folding, and as a further effect of the compression which produced it, the strata have been fractured along many lines parallel with the folds, and the rocks upon one side — generally the eastern — have been thrust upward and across the broken edges of those on the other side. A fault of this character passes along the western side of the Sequatchie Valley, and several formations which would normally occur there are entirely concealed.

Mineral resources.—These consist of coal, iron ore, limestone, building stone, and brick and tile clay. The productive coal-bearing formations, the Lookout and Walden sandstones, occupy the surface of the plateaus. They have an area within the district of about 400 square miles, and contain from one to three beds of workable coal. The beds in the Lookout are generally variable in position, extent, and thickness; those in the Walden are constant over large areas, and are worked on a considerable scale at various points along the eastern side of Walden Ridge. About 200 square miles of area of these upper coals occur within the district, on the Cumberland Plateau and in the eastern half of Walden Ridge. The most important iron ore in the district is the red fossil or Clinton ore, which occurs as a regularly stratified bed in the Rockwood shale. The bed is from three to five feet thick in Sequatchie Valley, but considerably thinner in the vicinity of Chattanooga and eastward.

Geologic Atlas of the United States, Folio 8, Sewanee, Tennessee, 1894.

This folio consists of nearly four pages of text, signed by Charles Willard Hayes, geologist; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° and 35° 30′ and the meridians 85° 30′ and 86°, and the territory it represents is wholly within Tennessee, embracing portions of Grundy, Sequatchie, Marion, Franklin, and Coffee counties. The district lies almost wholly within the western or plateau division of the Appalachian province. Crossing its southeastern corner is the Sequatchie Valley, located upon

the westernmost of the sharp folds which characterize the central or valley division of the province. The larger part of the district is occupied by the Cumberland Plateau, which has a gradual ascent toward the north, rising from an altitude of between 1700 and 1800 feet on the south to 1900 or 2000 feet on the north. The plateau is limited by a steep escarpment from 1100 to 1500 in height on the east and about 1000 feet in height on the west. Many streams have cut their channels backward into the plateau, forming deep, narrow caves, so that the escarpment forms an extremely irregular line. Small portions of Walden Ridge and Sand Mountain appear in the extreme southeastern corner of the district, these being plateaus similar to the Cumberland Plateau farther west. A small portion of the Sequatchie Valley occupies the southeastern part of the district, with an altitude of about 600 or 700 feet, while its northwestern portion is within the "highland rim" a broad terrace surrounding the lowlands of middle Tennessee and separating on the east from the Cumberland Plateau.

Geology.—The rocks appearing at the surface are of sedimentary origin, and include representatives of all the geologic periods from silurian to carboniferous. The Silurian formations, consisting of the Knox dolomite, Chickamauga limestone, and Rockwood shale, occur only, as narrow belts in the Sequatchie Valley. The same is true of the Devonian, which is represented by a single thin formation, the Chattanooga black shale. The Carboniferous formations occupy by far the larger part of the district, the Fort Payne chert and Bangor limestone forming the lower portions of the plateau escarpments and the highland rim, while the Lookout and Walden sandstones, belonging to the Coal Measures, form the summits of the plateaus.

The geologic structure of the region is in general extremely simple. The plateaus and the highland rim to the westward are underlain by nearly horizontal strata, while the Sequatchie Valley is upon a sharp, narrow fold, the beds dipping downward on either side beneath the adjoining plateaus. If the rocks which have been eroded from the top of this arch were restored, there would be a ridge several thousand feet in height in place of the present valley. In addition to the folding which the strata have suffered along this line, they have also been fractured, and the beds on the east have been thrust upward and across the edges of corresponding beds on the west of the fracture, so that along the western side of the valley the formations do not appear at the surface in their normal sequence.

Mineral resources.—These consist of coal, iron ore, limestone, building and road stone, and clays. The Coal Measures occupy an area within the district of about 500 square miles. Not all of this area, however, contains coal beds of workable thickness, while some portions contain two or three workable beds. The lower beds occurring in the Lookout sandstone, are variable in horizontal position, thickness, and extent, so that they cannot profitably be worked on a large scale; but they have been opened at many points, and supply an excellent fuel for local use. The Sewanee seam, which is found in the Walden sandstone, from 50 to 70 feet above its base, is the most important seam in the district. It has an average thickness of four to five feet over at least 80 square miles in the higher portions of the plateau, and is extensively mined for coking at Tracy and Whitwell. The iron ore of chief importance is the red fossil or "Clinton" ore, which occurs as a regularly stratified bed in the Rockwood shale. At Inman, in the Sequatchie Valley, it attains a thickness of 5.5 feet and is extensively mined.